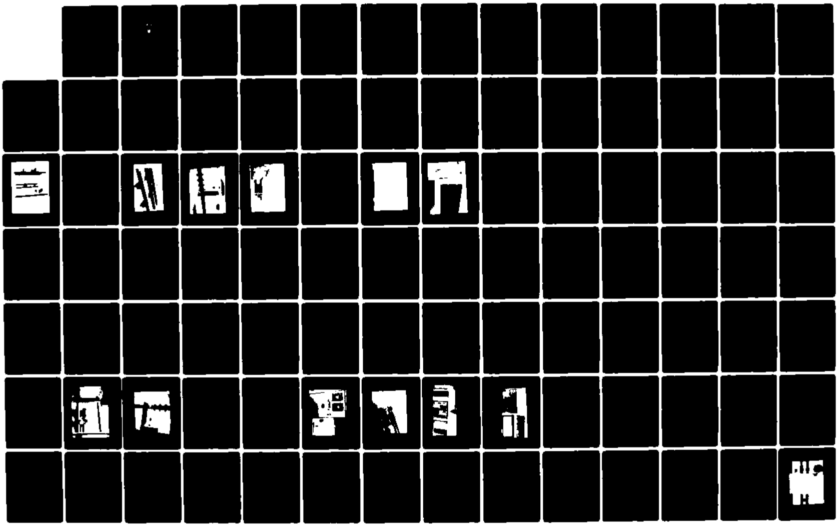
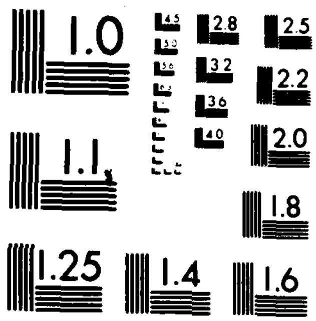
AD-A132 701 THE DESIGN OF A TEST PROCEDURE FOR THE MEASUREMENT OF ACOUSTIC DAMPING OF MATERIALS AT LOW STRESS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R A HEIDGERKEN SEP 83 1/3

UNCLASSIFIED F/G 17/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

THE DESIGN OF A TEST PROCEDURE FOR THE MEASUREMENT OF ACOUSTIC DAMPING OF MATERIALS AT LOW STRESS

by

Ricky A. Heidgerken

September 1983

Thesis Advisors: Y. S. Shin
J. Perkins

Approved for public release; distribution unlimited

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A132701	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Design of a Test Procedure for the Measurement of Acoustic Damping Materials at Low Stress		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ricky A. Heidgerken		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE September 1983
		13. NUMBER OF PAGES 232
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Acoustic Damping
HP-5451C
Material Damping
Damping Measurement Under Low Stress
Impulse Hammer Technique

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A procedure for measuring the viscous damping of relatively large plate material (up to 40 inches $\times$ 14 inches $\times$ 2 inches) was developed utilizing the Hewlett-Packard 5451C Fourier Analyzer and impulse hammer technique under very low stress conditions. Testing environment can be lab air or nondistilled water in the temperature range from 30° F to 90° F.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

#20 - ABSTRACT - (CONTINUED)

The test procedure includes modal analysis that is expandable to other geometric shapes and varied material such as high damping alloys and composites both metallic and non-metallic.

Approved for public release; distribution unlimited.

The Design of a Test Procedure for the Measurement of Acoustic Damping of Materials at Low Stress

by

Ricky A. Heidgerken
Lieutenant, United States Navy
B.S.M.E., University of Missouri, 1978

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

September 1983

Author: Ricky A. Heidgerken

Approved by: Young Shin, Thesis Advisor

Jeff Perkins, Co-Advisor

P. J. Marto, Chairman, Department of Mechanical Engineering

J. N. Dyer, Dean of Science and Engineering

ABSTRACT

A procedure for measuring the viscous damping of relatively large plate material (up to 40 inches × 14 inches × 2 inches) was developed utilizing the Hewlett-Packard 5451C Fourier Analyzer and impulse hammer technique under very low stress conditions. Testing environment can be lab air or nondistilled water in the temperature range from 30° F to 90° F.

The test procedure includes modal analysis that is expandable to other geometric shapes and varied material such as high damping alloys and composites both metallic and non-metallic.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I am very grateful to Professor Y.S. Shin whose expert advice, technical support and academic guidance resulted in my much greater understanding of the phenomenon of damping. I am also grateful to Professor Jeff Perkins, who initially gave me guidance on how to pursue my interest in material damping.

I want to express my sincere appreciation to Mr. Ernest J. Czyryca and the Naval Ship Research and Development Center in Annapolis, Md., for their encouragement and continued support of this project. I would also like to thank the Postgraduate School Research Foundation who made the purchase of the HP-5451C system possible and available to me for this project. Additionally, I would like to thank Doctor Sri Welaratna for his insight into the HP-5451C Fourier Analysis System. Finally, my wife, Ruthann, whose patience and administrative support was instrumental in the completion of this thesis.

I. INTRODUCTION

A. GENERAL

Ship silencing continues to be a major design requirement in the construction and operation of submarines and surface ships. It has been long established that both equipment and personnel are adversely affected by unwatned noise and vibration. In today's environment both subsurface and surface, with recent advances in acoustic devices the very survivability of the platform is directly related to own ship's noise. Weapon platforms must be quiet enough to escape detection by sophisticated passive sonar devices as well as quiet enough to prevent own ship's noise from interfering with detection and prosecution of enemy targets.

The more traditional approach to ship silencing has been, and continues to be, that of vibrations isolation. This approach requires that all sources of vibration to be placed on resilient energy-absorbing mounts. This results in a significant reduction in the transmission of vibrational energy from the equipment and main engines to the surrounding environment but is not totally satisfactory because these same mounts must serve as shock mounts. In addition, any resilient mount will have a peak efficiency in particular frequency range with decreasing efficiency both above and below that frequency range. The optimal solution would be to use

resilient mounts in conjunction with other methods of vibrational control to reduce the amount of vibration and noise generated as well as reducing the amount transmitted.

As with any design, today's ships are a compromise of requirements and cost considerations. However, the trend recently has been toward the design of equipment that is inherently quieter, which results in less noise and vibrational energy at the source. This current trend in design is currently being approached from many directions. Among these considerations are:

1. Extreme care in balancing of rotating machinery with consideration of vibrations during start up and coast down as well as steady state operation.
2. Selection of operating frequency as far removed from resonant frequencies as possible.
3. Close attention to component tolerances.
4. Possible use of high damping materials for machine elements as well as machine casings and load bearing structures.

The last category, use of high damping materials, is the furthest from being utilized to its maximum potential for noise and vibrational reductions.

Only recently has the designer even considered the internal capacity of a material alone with the traditional material properties of strength, fatigue resistance, toughness and corrosion resistance.

There are several commercially available high damping alloys that meet the strength requirements for most shipboard applications. It is recognized that each of the candidate materials may have unique properties that may cast doubt on their actual usefulness in the United States Navy. A more important problem exists, however. That is, the lack of a consistent method of measuring damping for a material under low stress, and high frequency range.

B. DAMPING

"Structural damping" refers to a structure's or structural component's capacity for dissipating energy, or, more precisely, to its capacity for removing from a structural vibration some of the energy associated with that vibration. The energy removed may be converted directly into heat, transferred to connected structures or ambient media [Ref. 1].

Damping has two primary effects: (1) It limits the steady-state motions of structures or systems in situations where these motions are controlled by an energy balance; and (2) It increases the rates at which the free (i.e., unforced) vibrations of structures decay.

Consider, for example, the classical lumped-parameter mass-spring dashpot system driven by a steady sinusoidal force that acts on the mass. For such a system it is possible to make the following observations: (1) For excitation frequencies that are considerably lower than the system resonance

frequency the applied force essentially is balanced by the spring force. The mass and dashpot here have virtually no effect. (2) For excitation frequencies that are considerably higher than the system resonance frequency, the applied force essentially is opposed by only the inertia force of the mass. In this case the spring and dashpot have virtually no effect.

(3) For excitation frequency near the system resonance frequency, the spring force and the inertia force essentially cancel each other, leaving only the dashpot (i.e., the damping element) to oppose the externally applied force. One may note that changes in the damping do not affect the system response for the first two of the above cases, but for an oscillatory force acting at the system's resonance, the vibration amplitude decreases with increasing damping.

In addition to the case of resonant or near-resonant excitation, there occur several other important steady-state or near-steady-state situations in which the responses of systems or structures are controlled by a balance between the energy input and the energy dissipations. These situations include cases of (1) broad-band excitation, and (2) spatially periodic excitation where the spatial period matches that of freely propagating waves. Because broad-band excitation generally encompasses several structural resonance frequencies, the structural responses of the excited modes, and each resonant modal response is controlled by damping.

If a structure (or a mechanical system) is deflected from its equilibrium position and then released, the structure vibrates with ever-decreasing amplitude on the result of damping, i.e., as the result of energy being removed from the oscillatory motions. Greater damping corresponds to the dissipation per cycle of a greater fraction of the vibratory energy, thus resulting in more tapid decay of the vibrations. In a somewhat similar manner, increased damping also results in the more rapid decay of freely traveling waves. For example, if a long beam is subjected to an oscillatory transverse force of a constant amplitude and frequency, such as near the center of the beam, then flexural waves travel away from the driving point in both directions. As the result of damping, the amplitude of these waves decreases with increasing distance from the point of application--with greater damping leading to lesser amplitudes at a given distance.

The practical consequences of effects mentioned above generally are the reasons one is interested in systems or devices that increase damping. Reductions in resonant or random responses result in decreased oscillatory stresses and increase in the fatigue life of structures, in the reliability of mechanical devices, and in mechanical impedance (which tends to improve the effectiveness of vibration isolation).

Reduction of the spatially resonant responses of a wall or panel leads to decreased sound transmission through that

structure for frequencies above the coincidence frequency. Increased attenuation of propagating waves results in lesser transmissions of vibrations to neighboring structures. More rapid decay of free vibrations reduces the "ringing" sound of structures, thus leading to less noise, particularly from structures excited by repetitive impacts. This also tends to reduce structural fatigue.

C. MEASURES OF DAMPING

Damping may be quantified in terms of any of the previously discussed primary effects. The corresponding commonly used measures of damping, defined below, are interrelated as follows: [Refs. 2,3]

$$\eta = \frac{\psi}{2\pi} = \frac{2.20}{f_n\,T_{60}} = \frac{\Delta_t}{27.3 f_n} = \frac{\delta}{\pi} = \frac{\Delta_\tau}{13.6} \qquad (1)$$

The loss factor η and damping capacity ψ are defined directly in terms of the cyclic energy dissipation; the damping capacity represents the fraction of the system's vibrational energy that is dissipated per cycle of the vibration, and the loss factor similarly is defined as the fraction of the system's energy that is dissipated per radian of the vibratory motion.

On the other hand, T_{60}, Δ_t, are related to the rate of decay of free vibrations. T_{60} denotes the reverberation time (in seconds), defined (in analogy to the related

room-acoustic measure) as the time within which the vibration level of a system vibrating freely at a frequency f_n (Hz) decreases by 60 dB (i.e., the amplitude decreases to 1/1000 of its original value). A related measure, decay rate Δ_t (dB/sec), represents the rate of reduction of the vibration (acceleration or displacement velocity) level. The logarithmic decrement δ is defined as the natural logarithm of the ratio of a peak excursion of a freely vibrating system to the peak excursion one cycle (period) later. The spatial decay Δ_τ (dB/wavelength) represents the reduction in the steady-state vibration level with distance that occurs along a long beam vibrating in flexure.

It should be noted that none of the measurements of damping depend on how the energy is dissipated. Within a cycle these measures make no reference to any damping mechanism. On the other hand, some other commonly employed measures of damping are defined on the basis of viscous damping (i.e., damping that results from a retarding force that is proportional to the velocity. The ratio of the magnitude of that force to the velocity is called the viscous damping coefficient and is commonly designated by c.

If a simple mass-spring-dashpot system (where the dashpot provides a viscous retarding force characterized by c) is deflected from equilibrium and released, it typically oscillates with ever decreasing amplitude. However, if c is made large enough, no oscillations occur. Instead, the system

creeps toward its equilibrium position, never traversing it. The smallest viscous damping coefficient for which this non-oscillatory behavior is obtained--i.e., the viscous damping that represents the dividing line between oscillatory and nonoscillatory behavior is called the critical (viscous) damping coefficient c_c. It obeys $c_c = 2\sqrt{km}$ where m denotes the mass and k the spring stiffness. The "damping ratio" c/c_c, also called the fraction of critical damping and often given in terms of "percent of critical damping", is widely used to indicate damping magnitudes.

Two other measures of damping are derived from the steady state behavior of an ideal linear mass-spring-dashpot system that is driven by a sinusoidal force of constant amplitude [Ref. 4]. The amplification at resonance, often called "the Q" of the system is defined as the ratio of the amplitude that results at resonance to the amplitude that is obtained if the force acts quasi-statically (i.e., a frequency considerably below resonance). The proportional bandwidth b takes account of the damping related broadening of the peak in a plot of response amplitude versus frequency; this nondimensional bandwidth is defined as f/f_n, where f denotes the difference between the two frequences (one above, and one below the resonance frequency f_n) at which the square of the response amplitude is one-half of its maximum value. For values of damping below critical, the aforementioned measure of damping are related to each other and to the previously discussed loss factor as:

$$\eta = \frac{c}{c_c} = \frac{1}{Q} = b \qquad (2)$$

D. DAMPING MECHANISMS

For linear, viscously damped systems, all of the measures of damping discussed previously are independent of the amplitude. Amplitude independence also occurs for other damping mechanisms, and approximate amplitude-independence occurs for almost all systems, provided the damping is relatively small. Thus, amplitude independence cannot be taken as an indication that a system is viscously damped; nevertheless, damping of systems with unknown energy dissipation mechanism is often characterized in terms of an equivalent viscous damping coefficient.

Indeed, much analysis is carried out with the (usually tacit) assumption that the damping is viscous--largely because viscous damping leads to linear differential equations that can be solved relatively easily. It is fortunate that for many practical problems, e.g., where only certain response maxima are of concern, the details of the damping mechanism are unimportant. Thus, one may obtain reasonable response predictions even with inaccurate damping force-versus-velocity representations. However, realistic damping models are required for the analysis of cases where one is interested in details of the response motions.

Unlike mass, a single physical phenomenon and stiffness, which results from a very few physical effects, damping may be caused by a great variety of phenomena. These phenomena include mechanical hysteresis (also called material damping or internal friction), electromagnetic effects (notably eddy currents), friction due to motion relative to fluids or solid surfaces, and energy transport to adjacent structural components or fluids (including by acoustic radiation). This great variety of phenomena that can produce damping generally make damping difficult to predict and to eliminate, but enables one to conceive a variety of means for increasing it.

II. NATURE OF THE PROBLEM

A. BACKGROUND

To date, the majority of damping research has been conducted on test specimens that are subjected to high stresses (i.e., torsional vibrations and vibrating cantilevered beams). For most United States Naval applications, structures and components are designed for operation at relatively low stresses.

Damping characteristics are shown to be highly stress dependent [Ref. 5]. Therefore, the damping values obtained at high stresses do not generally apply for most naval applications of ship silencing problems.

David W. Taylor Naval Ship Research and Development Center (NSRDC), Annapolis, Maryland is the focal point for testing and evaluating new high damping material for possible use for the United States Navy. Realizing the wide scope of the work necessary for the testing and evaluation of any new material, the author decided to approach NSRDC with a proposal to offer assistance in determining the damping of candidate material.

B. OBJECTIVE

To design a test procedure that allows the measurement of damping in a plate specimen at low stress with the following variables:

1. Plate specimen (40 inches × 14 inches × 1 inch) and 40 inches × 14 inches × 2 inches), or in proportionally reduced sizes.
2. Frequency: Damping testing will be conducted in the acoustic range (100-20,000 Hz).
3. Environment: Testing will be conducted in lab air and in nondistilled water. Temperature will range from 30°F to 90°F.

The test procedure includes a complete modal analysis that is expandable to other geometric shapes. Actual testing and verification of the procedure are conducted on the Hewlett-Packard 5451C Digital Fourier Analysis System. General information on the HP-5451C system is included in Appendix A.

C. SCOPE OF WORK TO BE COMPLETED

NSRDC has provided four specimens for testing and to establish baseline data for future work. The test specimens currently on hand are: A) Cast manganese bronze, code DEQ; B) Cast nickel-aluminum bronze, code FTC; C) Steel plate, HY-130, code FTW; and D) Aluminum alloy, 5086-H116, code ESX. It is anticipated that after baseline data has been compiled for both air and water tests that additional specimens will be provided by NSRDC. These additional specimens are expected to include high damping alloys such as Sonoston and Incramute, as well as constrained layer specimens and composites, both metallic and non-metallic.

For the purpose of this thesis the following work was completed: (A) design and construction of the test chamber, (B) design of a test procedure for the evaluation of damping of specimen provided by NSRDC, (C) complete tank characterization by impulse hammer techniques, (D) measurement of damping of the cast nickel-aluminum bronze, code FTC, specimen by impulse hammer technique. All of the above testing was completed in lab air at normal ambient temperature.

III. DESIGN OF TEST CHAMBER AND THEORY OF CHARACTERIZATION

To accomplish the aforementioned objectives four major steps must be accomplished: (A) design of a test chamber, (B) characterization of the test chamber, (C) design of experimental procedure of the measurement of damping, and (D) utilization of the above test procedure for damping measurement on a plate specimen supplied by NSRDC.

A. DESIGN OF TEST CHAMBER

Design of the test chamber was based on three major considerations; (1) size of the largest specimen, (2) weight of the largest specimen, and (3) environmental conditions desired for testing. In addition, the fixture to support the specimen had to hold the specimen rigid so that there would be no swinging.

The overall outside dimension of the chamber (Figure 1) was chosen to be a rectangular box 48 inches wide by 36 inches deep by 72 inches high. This allowed for ample clearance for the largest specimen (40 inches × 14 inches × 2 inches) on all surfaces and to limit the amount of reflected acoustic energy if acoustic absorption material was required on the inside surfaces. The test chamber was constructed from one quarter inch plate steel supported by a frame constructed from 2 inch steel thick wall square tubing. The 2 inch square tubing

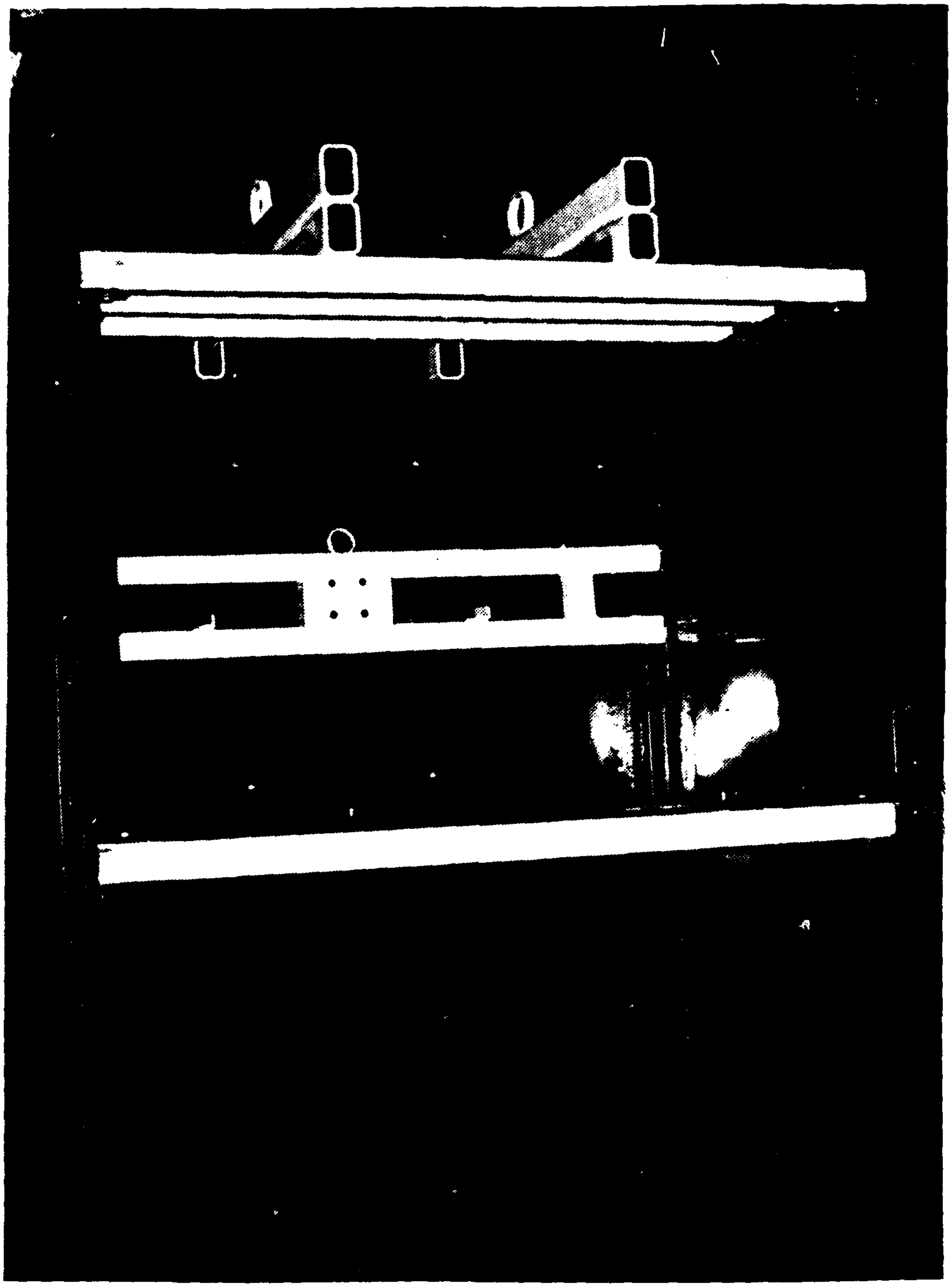


Figure 1. Experiment test chamber

was welded at all mating edges to give the desired rigidity and to prevent water entrapment (future corrosion problems).

The specimen fixture (Figure 2) was constructed from 3 inches × 2 inches thick wall steel tubing and is designed to give a deflection, from a 400 pound specimen, of less than 0.04 inch.

To accommodate various sized specimen the random frequency exciter base (Figure 3) can be adjusted within the 2 inch rectangular tubing frame work of the upper half of the rear panel (Figure 4). The random acoustic exciter can be adjusted from 8 inches below the specimen fixture to 24 inches below the specimen fixture. This feature allows for a wide variety of centered excitation from the end of a specimen plate to the center of a specimen plate.

To allow the removal and placement of various size specimen, the front panel of the test chamber is bolted to the test chamber frame and a water gasket is formed by using a RTV silicone adhesive sealant. Because of the bonding of the RTV all water test must be conducted with the steel front panel. For air testing the optional clear front panel may be used because no sealant is required.

The preservation of the test chamber was accomplished by sandblasting all steel parts, after protecting front panel and specimen fixture bolt threads, one spray paint coat of zinc chromate primer and one hand brushed top coat of enamel.

To allow testing in lab air and nondistilled water, the test chamber is water tight with a 1 inch, valved, drain

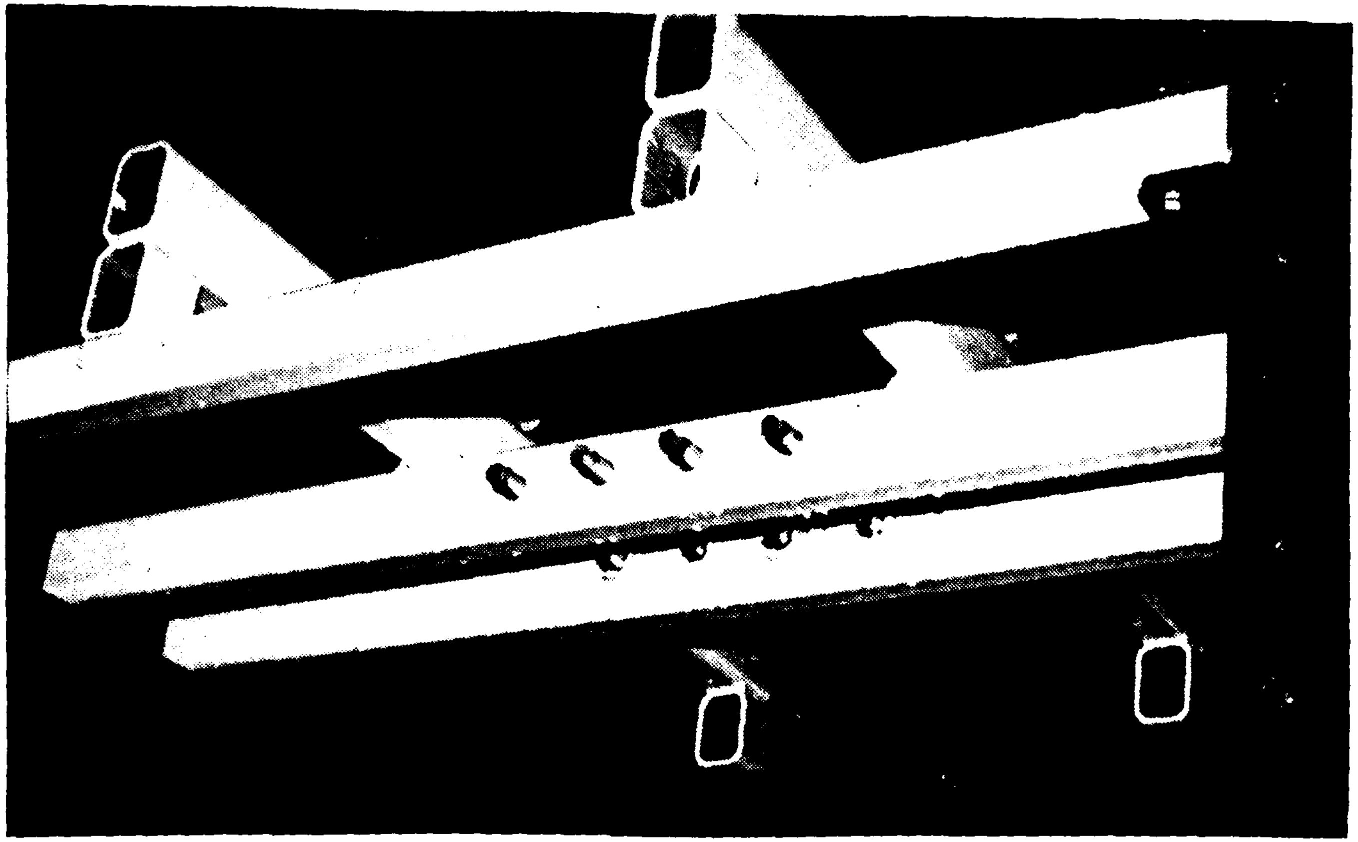


Figure 2. Detail of specimen support fixture

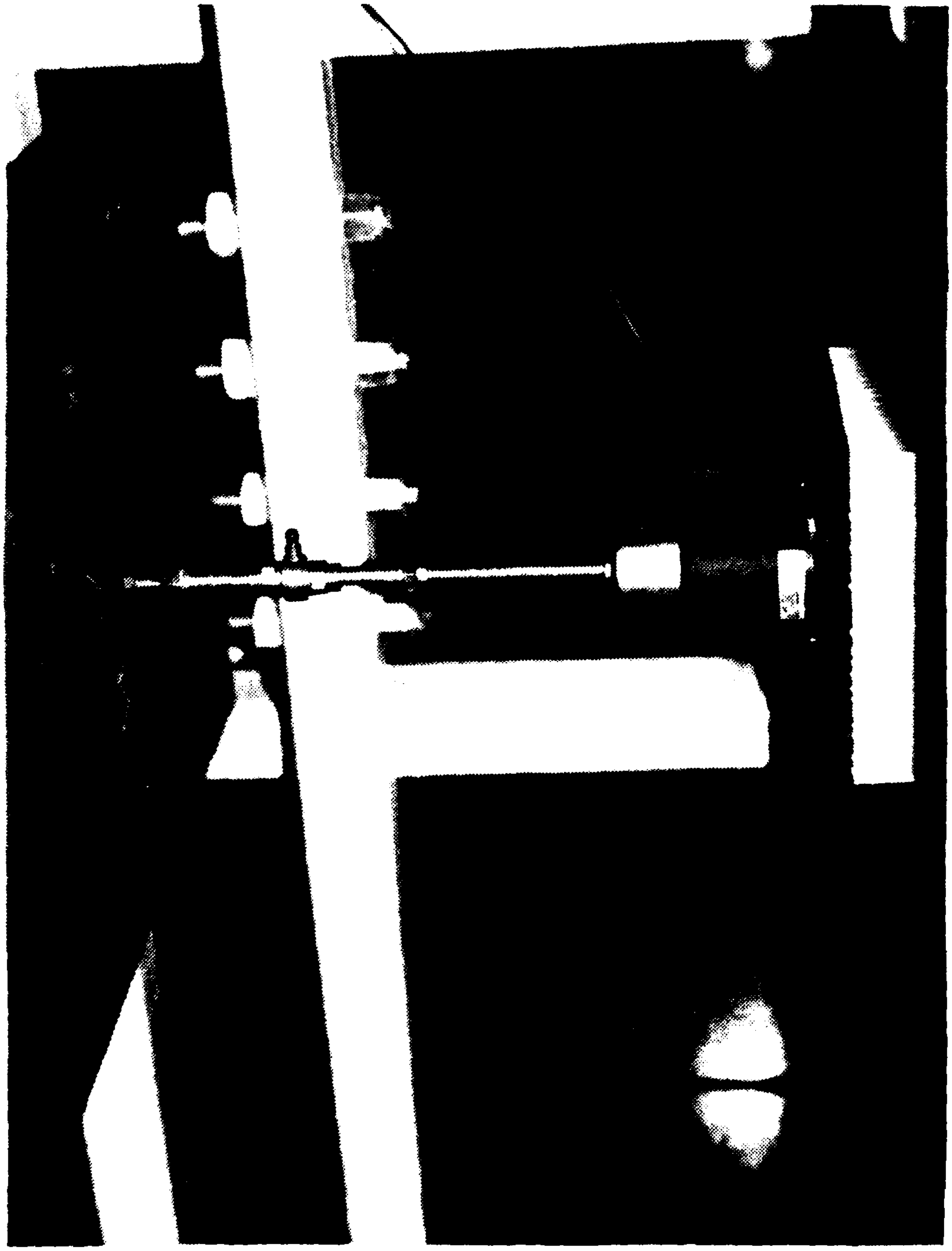


Figure 3. Specimen exciter base with support mechanism

Figure 4. Inside rear panel of test chamber

line near the bottom of the tank. Heating and cooling of the tank is accomplished by copper tubing (3/8 inch O.D.) coiled over entire outside surface of the back panel (Figure 5). The coils are spaced 3 inches apart and are 40 inches wide. To heat or cool the test chamber a mixture of 50% ethol glycol (automative) antifreeze is supplied from a storage tank (Figure 6) at the desired temperature and is pumped through the heating and cooling coil.

The entire test chamber is insulated with one and one half inches of rigid foam insulation, with the exception of the rear panel, which is insulated with standard residential batt insulation.

B. THEORY OF THE CHARACTERIZATION OF TEST CHAMBER

The characterization of the test chamber was accomplished by use of the impulse technique for structural frequency response testing [Ref. 7] and the Fourier transfer function capability of the HP-5451C Fourier Analyzer.

1. Theory of Frequency Response Function

The measurement of the frequency response function is the heart of modal analysis. The frequency response function H(f) is defined in terms of the single input/single output system, as the ratio of the Fourier transforms of the system output or response v(t) to the system input or excitation u(t), Equation (3).

$$H(f) = \frac{V(f)}{U(f)} \qquad (3)$$

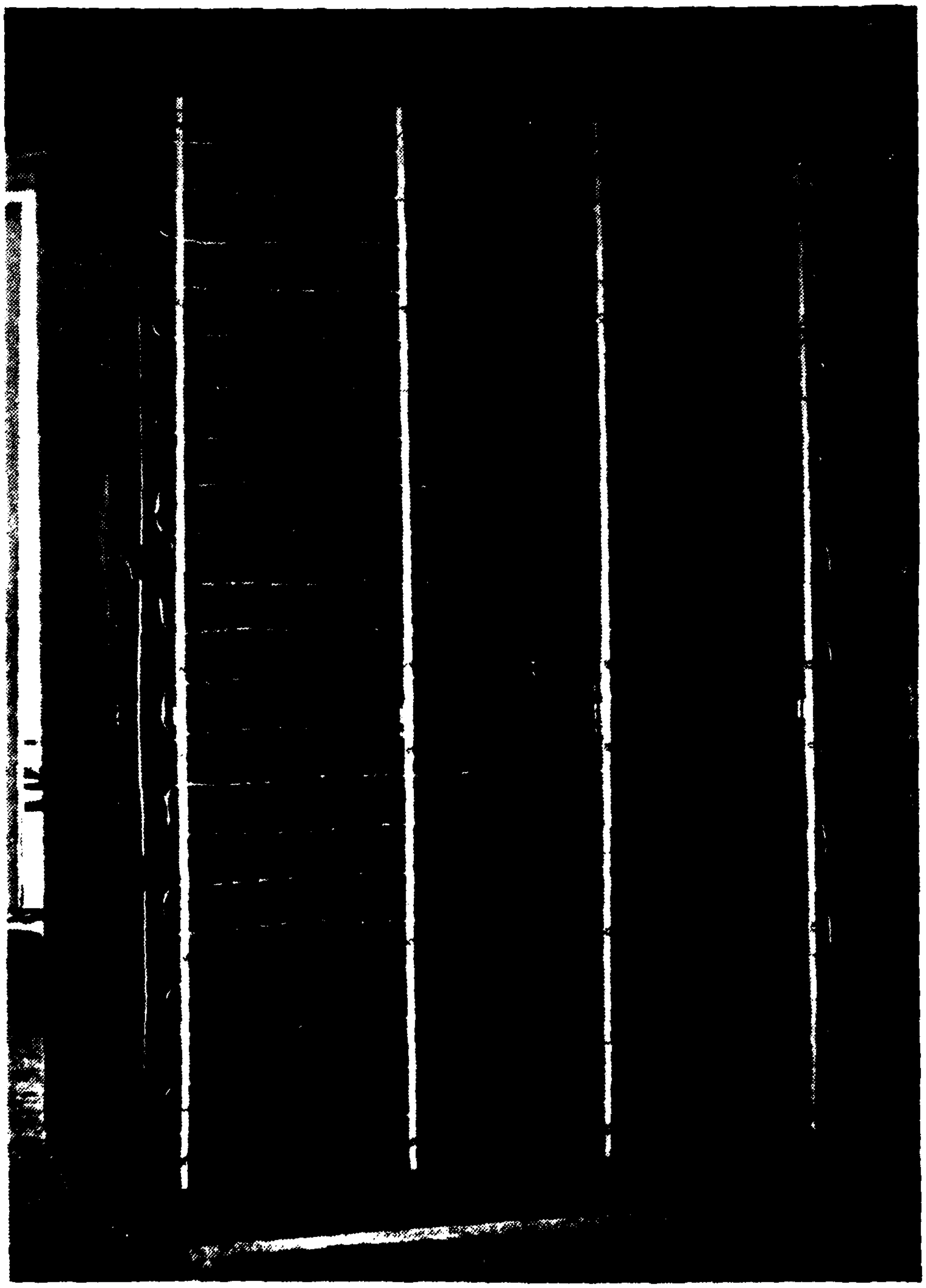


Figure 5. Cooling/heating coil on outside of rear panel

Figure 6. Cooling/heating water tank with pump, heater and controller

where:

$V(f)$ = Fourier transform of system output $v(t)$

$U(f)$ = Fourier transform of system input $u(t)$.

The only requirements for a complete description of the frequency response function are that the input and output signals be Fourier transformable, a condition that is met by all physically realizable systems, and that the input signal be non-zero at all frequencies of interest. If the system is nonlinear or time-variant, the frequency response function will not be unique, but will be a function of the amplitude of the input signal in the case of a nonlinear system and a function of time in the case of a system with time-varying properties.

The frequency fesponse function may be computed directly from the definition as the ratio of the Fourier transforms of the output and input signals. However, better results are obtained in practice by computing the frequency response function as the ratio of the cross-spectrum between the input and output to the power spectrum of the input, Equation (4). This relationship is derived by multiplying the numerator and denominator of the right-hand side of Equation (1) by the complex conjugate of the input Fourier transform.

$$H(f) = \frac{G_{uv}(f)}{G_u(f)} \tag{4}$$

where:

$G_{uv}(f)$ = $U^*(f)V(f)$, cross-spectrum between $u(t)$ and $v(t)$

$G_{uv}(f)$ = $U^*(f)U(f)$, power spectrum of $u(t)$

U^* = complex conjugate of $U(f)$.

The usefulness of this form of the frequency response function can be seen by considering the practical single input/single output measurement situation, where $m(t)$ and $n(t)$ represent noise at the input and output measurement points, respectively.

The measured frequency response function $H'(f)$ is given by the equation:

$$H'(f) = \frac{Y(f)}{X(f)} = \frac{V(f) + N(f)}{U(f) + M(f)} \tag{5}$$

where the upper case letters denote the Fourier transform of the corresponding time domain signals.

In this form, the measured frequency response will be a good approximation of the true frequency response only if the measurement noise at both the input and output measurement points is small relative to the input and output signals. Multiplying the numerator and denominator of the right-hand side of Equation (5) by the complex conjugate of $X(f)$ yields

$$H'(f) = \frac{G_{uv}(f) + G_{un}(f) + G_{mv}(f) + G_{mn}(f)}{G_{u}(f) + G_{um}(f) + G_{mn}(f) + G_{m}(f)} \tag{6}$$

Now, if the measurement noise signals m(t) and n(t) are noncoherent with each other and with the input signal u(t), then the expected value of the cross-spectrum terms involving m and n in Equation (6) will equal zero, yielding

$$H'(f) = \frac{G_{uv}(f)}{G_u(f) + G_m(f)} = \frac{H(f)}{1 + \frac{G_m(f)}{G_u(f)}} \tag{7}$$

where H(f) is the desired true frequency response function.

Thus, if the noise-to-signal ratio at the input measurement point $[G_m(f)/G_u(f)]$ is much less than 1, the measured frequency response will closely approximate the desired true frequency response function.

It should be pointed out here that there is an inherent bias error associated with the computation of the cross-spectrum and the magnitude of this bias error is inversely proportional to the number of averages in the computation. Thus, the greater the measurement noise, the greater the number of averages required to approach the expected value of the cross-spectrum between the input and the output measurement signals. With measurement techniques employing many averages, the bias error can usually be reduced to an insignificant level so that it is only necessary to minimize the noise in the measurement of the input signal. However, if there is significant measurement noise and only a few averages are used, then the computed values of the cross-spectrum terms

involving the noise signals in Equation (6) can be large relative to the true cross-spectrum, with resulting large errors in the measured frequency response function. In general, only a few averages are used in the impulse technique; otherwise, one of its major advantages--its speed--is lost. Therefore, it is important to minimize measurement noise in both the input and output signals when using the impulse technique. The cross-spectrum bias error and its effects are discussed in more detail in Reference 8.

Coherence Function. There is another important reason for computing the frequency response function in terms of the cross-spectrum: it allows the computation of the coherence function between the input and output signals. The coherence function is defined by the equation

$$\gamma_{xy}^2(f) = \frac{|G_{xy}(f)|^2}{G_x(f)G_y(f)} \tag{8}$$

According to the definitions of the power spectrum and the cross-spectrum, the coherence function will be identically equal to 1 if there is no measurement noise and the system is linear. The minimum value of the coherence function, which occurs when the two signals are totally uncorrelated, is 0. Thus, the coherence function is a measure of the contamination of the two signals in terms of noise and nonlinear effects, with very low contamination indicated for values close to 1.

Since the cross-spectrum is included in the definition of the coherence function, the cross-spectrum bias error must be reduced to an acceptable level if a good statistical estimate of the coherence function is to be achieved. As stated above, the number of averages used in the impulse technique is usually not great enough to significantly reduce the bias error. However, the coherence function is still useful for indicating the importance of noise in the impulse technique. This is because noise in the signals causes variance in the value of the coherence function with frequency. This effect is illustrated in the section on measurement procedures.

2. Display of Frequency Response

The frequency response function is complex--that is, it has associated with it both magnitude and phase. Therefore, it can be displayed in a number of forms, including magnitude and phase versus frequency, real and imaginary magnitudes versus frequency, and imaginary magnitude versus real magnitude. Each of these types of displays has its own particular usefulness. The most common type of display for structural frequency response data is magnitude and frequency plotted logarithmically. This type of display, with the magnitude in terms of compliance (ratio of displacement to force) is called a Bode plot. In this form of the frequency response function, resonances occur as peaks in compliance plots (points of maximum dynamic weakness) and all resonance peaks of equal damping have the same width regardless

of resonance frequency. Lines of constant dynamic stiffness have zero slope, and mass-dominated frequency response lines have a -12 dB-per-octave slope. Resonances occur as nearly circular arcs in the complex plane (real versus imaginary plot) with frequency increasing in a clockwise direction around the arc. In the case of real normal modes (which occur in systems with relatively low damping and with resonances well-separated in frequency), each resonance arc is approximately tangent with, and lies below, the real axis and is symmetric about the imaginary axis when the frequency response is expressed as compliance. The complex plane plot is useful when certain types of analytical curve fitting operations are being performed on the frequency response data. The plots of the real and imaginary magnitudes of frequency response versus frequency are most useful when dealing with real normal modes. In this case the resonances will occur as peaks in the imaginary magnitude plot and the real magnitude will pass through zero at the resonance frequency when the frequency response is expressed as compliance.

The frequency response characteristics of a structural element are determined by measuring a set of cross-frequency response functions as discussed in Reference 9. The cross-frequency response functions may be obtained by exciting at one location on the structure and measuring response at various locations, or by measuring the response at a single location to excitation at various locations. The resulting

frequency response functions comprise one column of the transfer matrix in the first case, and one row of the transfer matrix in the second case. Either set will, in general, completely define the modal characteristics of the structural element. In mathematical terms the set of frequency response functions yields the eigenvalues and eigenvectors, which are, in general, complex terms. The real part of an eigenvalue is the damping and the imaginary part is the frequency associated with a given resonance. Each eigenvector defines a resonance mode shape.

With real normal modes, each point on a structure is either exactly in-phase or exactly 180 degrees out-of-phase with any other point at the resonance frequency. Certain types of damping which are often encountered in practice will cause the eigenvectors to have non-zero imaginary components, resulting in complex mode shapes. When a mode is complex, the relative phase associated with a point on a structure is some value other than 0 or 180 degrees, with the result that node lines (lines of zero deflection) are not stationary. Precise description of complex modes requires that some type of analytical curve fitting technique be applied to the frequency response data.

The frequency response function of an operating system can be computed if the system input and output signals meet previously stated requirements of Fourier transformability and non-zero value, assuming the system input and response

can be measured. However, in practice there are usually multiple inputs to the system--either several inputs at different locations or inputs in more than one direction at a given location. In the case of multiple coherent inputs, the complexity of the analysis is greatly increased. For this reason, and the difficulty of accurately monitoring operating inputs, frequency response measurements are usually made by applying the system input "artificially" through some type of exciter. It is in the form of the input signal and the way it is applied to the structure that the wide variety of frequency response testing techniques arises.

The usefulness of the impulse technique lies in the fact that the energy in an impulse is distributed continuously in the frequency domain rather than occurring at discrete spectral lines as in the case of periodic signals. Thus, an impulse force will excite all resonances within its useful frequency range. The extent of the useful frequency range of an impulse is a function of the shape of the impulse and its time duration. For a square pulse the frequencies of the zero crossings are at integral multiples of the inverse of the time duration of the impulse, illustrating the very important inverse relationship between the time duration of an impulse and its frequency content.

The useful frequency range of an impulse is also a function of the shape of the impulse. By varying the weight and hardness of an impacting device and the manner in which

the impact is applied, the shape and time duration of the impulse produced can be varied to suit the measurement requirements.

a. Nonlinearities in the Structures

Excitation of a nonlinear system by a pure-random signal will yield the best estimate (in a mean-square sense) of the linear system response. Excitation by a pure sine wave is also useful for studying nonlinear systems because it allows precise control of the input spectrum level. However, the impulse technique, because of its very high ratio of peak level to total energy, is particularly ill-suited for testing nonlinear systems. Therefore, it is important to understand the various types of nonlinearities that can occur in structural systems and to be able to recognize nonlinearities in measured frequency response functions.

One of the most common types of nonlinearities encountered in structures is that due to clearance between parts. This type of nonlinearity is frequently encountered, for example, when testing gear systems and shafts mounted in bearings. The effects of this type of nonlinearity on measured frequency response functions when using impulse excitation are poor estimates of static stiffness values and poor repeatability of the frequency response estimates. Also, the apparent damping in the estimates will be greater than the actual examples.

The best method of dealing with this type of nonlinearity is to preload the system to take up clearances. Care must be taken when this is done, however, because any preload will change the boundary conditions of the structure and can itself lead to erroneous frequency response estimates. The usual approach is to apply the preload through a very soft spring so that the resonances associated with the preload lie below the frequency range of interest.

Another type of nonlinearity that is frequently encountered is nonlinear damping. Nonlinear damping effects are usually associated with joints in the structure, where the damping is a function of the relative displacement at the joint. In general, the frequency response estimates obtained by the impulse technique will agree most closely with those obtained with a low level of continuous excitation. However, if the point of excitation is close to a location where nonlinear damping occurs, there will be high relative motion at that location, and the apparent damping in the measured frequency response will be high. In systems with low damping, this will give the measured frequency response a discontinuous appearance, due to the varying level of damping as the response to the impulse attenuates with time.

The third type of nonlinearity that commonly occurs in structures is load-sensitive stiffness, where the spring rate of elastic elements either increases or decreases with load. The most direct way to identify this type of

nonlinearity is to measure frequency response as a function of static preload and observe the change in resonance frequencies.

b. Signal Processing

The particular characteristics of an impulsive force signal and the resulting structural response signal make the impulse technique especially susceptible to two problems: noise and truncation errors. While these problems occur to some extent with other frequency response testing techniques, their unique importance in the impulse technique requires special signal processing methods.

It was pointed out in the previous section that the usable frequency range for an impulse depends on the shape and time duration of the impulse. In order to insure that there is sufficient force over the frequency range of interest, it is necessary that the first zero crossing of the Fourier transform of the impulse be well above the maximum frequency of interest. For a given time duration the first zero crossing occurs at the lowest frequency for a square pulse. For that type of pulse the first zero crossing occurs at a frequency equal to the inverse of the time duration. A good rule of thumb, then, is to insure that the duration of the impulse is less than $2\Delta t$, where t is the sampling interval in the analog-to-digital conversion process. This would put the first zero crossing of the Fourier transform of a square pulse at the Nyquist folding frequency, and the

first zero crossing of other pulse shapes above the Nyquist folding frequency.

The sample length is equal to $N\Delta t$ where N is the number of digital values in each sample. A typical value of N is 1024. Thus, the duration of the impulse is very short relative to the sample length. This means that the total energy of noise represented in the time-sample can be on the order of the energy of the impulse, even for high signal-to-noise ratios. The noise problem is further aggravated when employing the zoom transform, which yields increased resolution in a given frequency band by effectively increasing the sample length.

With other techniques, the effects of noise are reduced by averaging the power spectrum and cross-spectrum functions prior to the computation of the frequency response function. However, only a few averages are usually used in the impulse technique. Otherwise, the time advantage of the technique is lost. Therefore, special time-sample windows have been developed for the impulse technique.

At first thought it might seem appropriate to just set all time-sample values beyond the impulse to zero, since it is known that the true signal value after the impulse is zero. However, this would be equivalent to multiplying the signal by a narrow rectangular window. In applying any type of window, it is important to keep in mind that multiplication by a window in one domain is equivalent to

convolution of the Fourier transforms of the window and the data in the other domain, resulting in distortion of the transformed signal. This distortion will be minimized by minimizing the width of the main lobe of the window transform and suppressing its side lobes. However, there is a fundamental conflict between these requirements and the reduction of noise in the time-sample because both the width of the main lobe and the amount of noise reduction are inversely proportional to the width of the window in the time domain. To further complicate the situation, suppression of the side lobes is generally achieved at the expense of broadening the main lobe.

A good compromise has been arrived at in practice in the form of a window with unity amplitude for the duration of the impulse and a cosine taper, with a duration of 1/16 of the sample time, from unity to zero.

Noise problems may also be encountered in the response signal, particularly when dealing with heavily damped systems and when using zoom transform analysis. In both cases the duration of the response signal may be short relative to the total sample time, so that noise may comprise a significant portion of the total energy in the time-sample even with relatively high signal-to-noise ratios. Another error in the response signal that is encountered when testing lightly damped structures occurs when the response signal does not significantly decay in the sample window. In this case

the resulting time-sample is equivalent to multiplying the true response signal by a rectangular window, with the result that the frequency resolution may not be sufficient to resolve individual resonances.

An exponential window has been developed to reduce the errors that occur in both situations described above. The window decays exponentially from 1 to a value of 0.05 in the sample time. It can be applied directly to the time-sample of the response signal or to the impulse response function. As with all windows, the exponential window does change the resulting measured frequency response function; but its only effect is to increase the apparent damping in the resonances. It does not change the resonance frequencies and, because the effect of the exponential window is the same on all frequency response measurements, it will not alter the measured mode shapes if applied to all measured frequency response functions. In addition to reducing noise and truncation errors, the exponential window will also reduce errors which often occur when testing lightly damped systems in which the damping varies with the measurement position on the structure.

Because the exponential window increases the apparent deamping in the resonance modes, there is a tendency of the window to couple closely spaced resonance modes. Zoom transform analysis may be required in some cases to allow sufficient resolution of closely spaced modes when using the exponential window.

Zoom transform analysis is discussed in some detail along with several examples in Reference 9. It is a very valuable tool in impulse testing, as it is in other frequency response measurement techniques. The effect of the zoom transform is to increase the resolution of the analysis by allowing independent selection of the upper and lower frequency limits of the analysis band. With the zoom transform, for example, it is possible to perform an analysis in the frequency range from 900 to 1000 Hz as opposed to the corresponding base-band range of 0 to 1000 Hz, resulting in a 10-to-1 increase in resolution, for a given sample size N, in the 900 to 1000 Hz band. Because of greatly increased resolution possible with the zoom transform, it can be effectively used in frequency response testing to separate closely spaced resonance modes.

There are two important effects of the zoom transform in the impulse technique, both associated with the resulting increase in sample time. The first effect is to make possible much better estimates of damping in lightly damped systems. This is due to the reduction of truncation errors in the sampled response signal. The second effect, mentioned previously, is aggravation of the noise problem in both the input and response signals. The second effect makes it essential that force and response windows be applied to the data in most cases when using the zoom transform with the impulse technique.

3. HP-5451C Fourier Transfer Function

A transfer function, as determined by the HP-5451C Fourier Analyzer, is a mathematical description of a system. It can be defined as:

$$\text{transfer function} = \frac{\text{Fourier transform of output}}{\text{Fourier transform of input}}$$

or equivalently,

$$\text{transfer function} = \frac{\text{average cross power spectrum of input and output}}{\text{average power spectrum of input}}$$

The coherence function measures the degree of causality between any two signals. It can, therefore, be used to check the validity of the transfer function. When a transfer function is computed it may not be obvious that there are extraneous inputs, or that the system is nonlinear. Both of these factors would introduce error in the computed transfer function. The "Transfer Function" program of the HP-5451C is used to compute the transfer and coherence functions. A program flow chart and a program listing are provided in Appendix B.

IV. THEORY OF THE TEST PROCEDURE TO MEASURE DAMPING

The design concept of the experimental procedure is based on the Hewlett-Packard modal analysis software specifically designed for the HP-5451C Fourier Analyzer. The theory of the complex modes for damped oscillatory mechanical systems is described below, much of which is explained in greater detail in the Modal Analysis Operating and Service Manual (Option 402).

A. MODAL THEORY OF OPERATION [REF. 6]

Assume that the motion of a physical system can be described by a set of n simultaneous second-order linear differential equations in the time domain, given by,

$$M\ddot{x} + C\dot{x} + Kx = f \qquad (9)$$

where the dots denote differentiation with respect to time.

$$f = f(t)$$

is the applied force vector, and

$$x = x(t)$$

is the resulting displacement vector, while M, C, and K are the $(n \times n)$ mass, damping, and stiffness matrices respectively.

Our attention will be limited to symmetric matrices, and to real element values in M, C, and K.

Taking the Laplace transform of the system equations gives

$$B(x)X(s) = F(s), \tag{10}$$

where:

$$B(s) = Ms^2 + Cs + K \tag{11}$$

Here s is the Laplace variable, and F(s) is the applied force vector and X(s) is the resulting displacement vector in the Laplace domain. B(s) is called the system matrix, and the transfer matrix H(s) is defined as

$$H(s) = B(s)^{-1} \tag{12}$$

which implies that

$$H(s)F(s) = X(s) \tag{13}$$

Each element of the transfer matrix is a transfer function. The elements of B are quadratic functions of s, and since $H = B^{-1}$, it follows that the elements of H are rational fractions in s, with det(B) as the denominator. Thus, H(s) can always be represented in partial fraction form.

If it is assumed that the poles of H, i.e., the roots of det(B) = 0, are of unit multiplicity, then H can be expressed as

$$H(s) = \sum_{k=1}^{2n} \frac{a_k}{s-p_k}, \qquad (n \times n) \tag{14}$$

The poles occur at $s = P_k$ (zeros of det(B)), and each pole has n $(n \times n)$ residue matrix a_k associated with it. For an n^{th} order oscillatory system, there will always be 2n poles, but they will appear in complex conjugate pairs. Each complex pair of poles causes a mode of vibration in the structure. The poles are complex numbers expressed as

$$P_k = -\sigma_k + i\omega_k \tag{15}$$

where σ_k is the damping coefficient (a negative number for stable systems), and ω_k is the natural frequency of oscillation. The resonant frequency is given by

$$\Omega_k = \sigma_k^2 + \omega_k^2 \qquad \text{(rad/sec)} \tag{16}$$

and the damping factor is

$$\zeta = + \frac{\sigma_k}{\Omega_k} \tag{17}$$

These coordinates are shown in Figure 7. When $\zeta = 1$, mode (k) is said to be critically damped. It is also possible that $\zeta > 1$. For this case the poles of mode (k) lie along the real (or damping) axis in the S-plane and it is said to be super-critically damped.

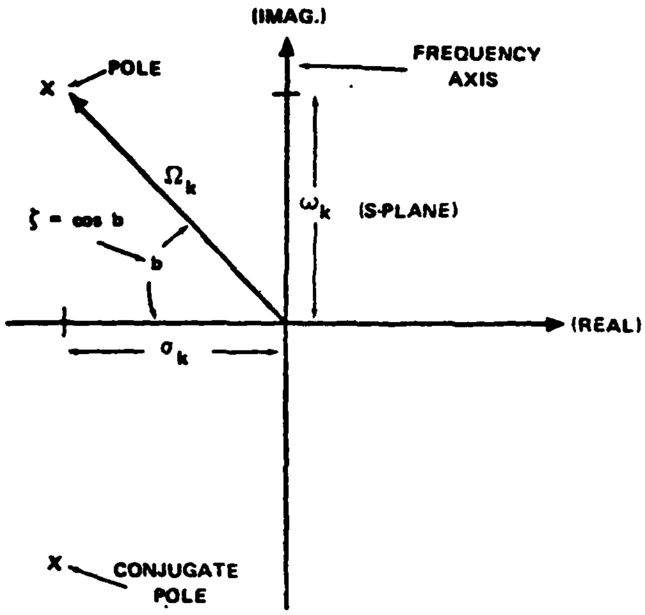


Figure 7. Poles of a Mode (k)

Modal vectors (u_k) are now defined as solutions to the homogeneous equation

$$B_k u_k = 0 \tag{10}$$

where:

$$B_k = B(p_k)$$

for all k = 1,...,2n.

In addition, pre-multiplying B times the equation (14) for H(s), multiplying by the scalar $(s-p_k)$ and letting $s = p_k$ gives

$$B_k a_k = 0 \tag{19}$$

It follows by comparison of (10) with (19) that every column of a_k must contain the modal vector u_k, for each $k = 1,\ldots,2n$.

Similarly, post multiplying B times the equation (14) for H(s), multiplying by the scalar $(s-p_k)$, and letting $s = p_k$ gives

$$a_k B_k = 0 \tag{20}$$

for each $k = i,\ldots,2n$. This can be rewritten as

$$B_k^t a_k^t = 0 \tag{21}$$

where t denotes the transpose.

But B_k, and hence a_k, is assumed to be symmetric so equation (21) is the same as (19) and it follows that each row of a_k must also contain the vector u_k for each $k = 1,\ldots,2n$.

In order to satisfy the above conditions a_k must have the form

$$a_k = A_k u_k u_k^t \qquad (n \times n) \tag{22}$$

where A_k is a scalar.

This pervasiveness of the modal vectors throughout the transfer function matrix is evidence of the so-called global property of a mode of vibration.

In these terms, H can be rewritten as

$$H = \sum_{k=1}^{2n} \frac{A_k}{s-p_k} u_k u_k^t \tag{23}$$

and this is easily written in matrix form as

$$H = U\ L\ U^t \qquad (n \times n) \tag{24}$$

where the columns of U comprise the u_k modal vectors:

$$U = [u_1\ u_2\ \ldots\ u_{2n}]\ , \qquad (n \times 2n) \tag{25}$$

and L is a diagonal matrix containing all s dependence

$$L = \begin{bmatrix} \frac{A_1}{s-p_k} & & \\ & \ddots & \\ & & \frac{A_{2n}}{s-p_{2n}} \end{bmatrix} \quad (2n \times 2n)\ . \tag{26}$$

Pre-multiplying H by U^t, equation (13), can be written as

$$(U^tUL)(U^tF) = (U^tX) \tag{27}$$

so that U^t transforms the spatial vectors F and X to vectors U^tF and U^tX in modal coordinates. Similarly U^tUL is the modal representation of H. Since $B(P_k)u_k = 0$, it follows that $B(P_k^*)u_k^* = 0$, so the modal vector associated with the conjugate pole (P_k^*) is u_k^* (the conjugate of u_k).

Thus, the above U matrix always contains conjugate pairs of modal vectors, and the L matrix always contains elements corresponding to conjugate pole pairs along its diagonal.

If U_1 is defined as that $(n \times n)$ part of U associated with positive poles, then U_1^* will correspond to the negative poles. Similarly, L can be broken into two parts, L_1 comprising the positive poles, and L_2 comprising the negative poles. It can then be represented

$$H \;=\; U_1 L_1 U_1^* + U_1^* L_2 U_1^{*t} \qquad (28)$$

or in partitioned form as

$$H \;=\; [U_1 \,\vdots\, U_1] \begin{bmatrix} L_1 & 0 \\ 0 & L_2 \end{bmatrix} [U_1^t \,\vdots\, U_1^{*t}] \qquad (29)$$

Each of these sub-matrices is $(n \times n)$ and only L_1 and L_2 are functions of s.

$$L_1 = \begin{bmatrix} \frac{A_1}{s-p_1} & & & \\ & \cdot & & \\ & & \cdot & \\ & & & \cdot & \\ & & & & \frac{A_n}{s-p_n} \end{bmatrix}, \quad L_2 = \begin{bmatrix} \frac{A_1}{s-p_1} & & & \\ & \cdot & & \\ & & \cdot & \\ & & & \cdot & \\ & & & & \frac{A_n}{s-p_n^*} \end{bmatrix}$$

(30)

Then H can be written as:

$$H = \sum_{k=1}^{n} u_k u_k^t \frac{a_k}{s-p_k} + u_k^* u_k^{*t} \frac{A_k}{s-p_k^*} \tag{31}$$

Each element of the H matrix has a different zero in the S-plane, depending upon the values of A_k and u_k at each point, but the poles of each element of H are common, and occur at $s = p_k$ and $s = p_k^*$.

1. Identification of Modal Parameters

Because of the form of the a_k matrix, only one row or column of the transfer matrix need be measured and analyzed, since all processes of measuring the transfer matrix, the unknown parameters in equation (14) (i.e., the complex values of p_k and the complex values of the elements of one row or column or the residue matrix a_k) are identified.

Once one row or column of a_k has been identified, it is then possible to construct the rest of the rows and columns in a_k. For example, if the q^{th} column of a_k is given by a_{kq}, then

$$a_{kq} = A_k u_{qk} u_k \tag{32}$$

where uq_k is the q^{th} component of the modal vector. Since $A_k u_{qk}$ is a scalar, it is clear that the vector of modal residues a_{kq} is proportional to the modal vector u_k, for each $k = 1,\ldots,2n$.

Since A_k is a scaling constant it can be assumed that either $A_k = 1$ or the square root of $u^t u = 1$ without loss of generality in the following derivation.

Suppose $A_k = 1$, then

$$a_k = u_k u_k^t \tag{33}$$

and for the q^{th} column or row of a_k

$$a_{kq} = u_{qk} u_k \tag{34}$$

Hence the q^{th} element of a_{kq} is

$$a_{kqq} = (u_{qk})^2 \tag{35}$$

Since u_{qk} is a scalar, equation (34) can be rewritten

$$u_k = \frac{a_{kq}}{u_{qk}} \tag{36}$$

and substituting this back into (33) gives

$$a_k = \frac{a_{kq} a_{kq}^t}{(u_{qk})^2} \tag{37}$$

or using equation (35)

$$a_k = \frac{a_{kq} a_{kq}^t}{a_{kqq}} \tag{38}$$

Hence the entire matrix a_k and therefore, the entire transfer function matrix H(s) can be constructed once one row or column of residues a_{kq} has been identified as well as the pole locations pk, for each k = 1,...,2n. The residue a_{kqq}

is at the driving point of the structure, i.e., the point where the structure is excited.

2. Impulse Response of Complex Modes

It has been shown that a mode of vibration is represented by a complex conjugate pair of poles and a complex conjugate pair of modal vectors in the transfer matrix. Hence for a single mode of vibration (k) the transfer matrix is written

$$H_k(s) = \frac{a_k}{s-p_k} + \frac{a_k}{s-p_k} \qquad (n \times n) \tag{39}$$

It is convenient to remove a factor of 2i from the residue matrix, that is to define another residue matrix r_k such that

$$r_k = 2_i \; a_k \tag{40}$$

Then the transfer matrix is written as

$$H_k(s) = \frac{r_k}{2i(s-p_k)} - \frac{r_k}{2i(s-p_k)} \tag{41}$$

Each component of this matrix exhibits the rectangular (or coincident--quadrature) from shown in Figure 8 for each valued r_k.

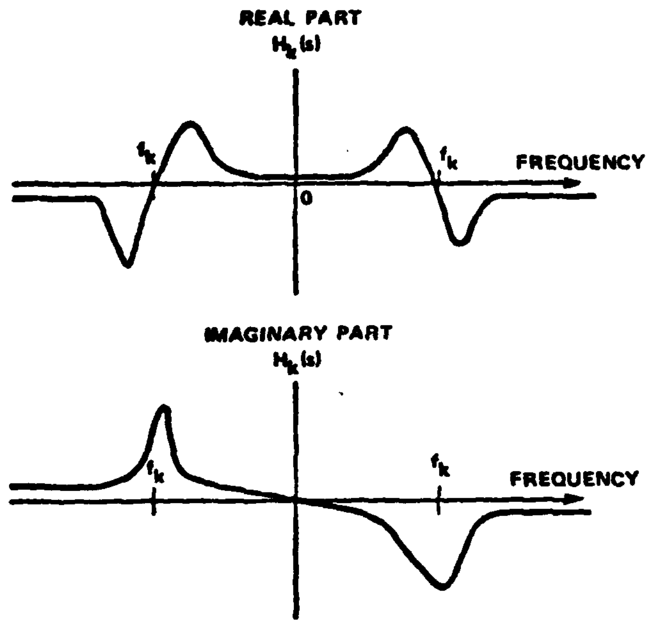


Figure 8. Transfer Function for a Single Mode of Vibration

Taking the inverse Laplace transform of (41) gives

$$x(t) = \frac{r_k}{2i} e^{p_k t} - \frac{r_k^*}{2i} e^{p_k^* t} \tag{42}$$

$$x(t) = |r_k| e^{-\sigma_k t} \operatorname{sine}(\omega_k t + \alpha_k) \tag{43}$$

where α_k = the angle of the complex residue r_k.

Equation (43) is the impulse response of a complex mode of vibration. The mode shape is defined by the magnitude $|r_k|$ and the phase angle (α_k) at each point on the structure.

The mode shape matrix is printed in the Modal System in terms of these magnitude and phase angles.

3. Modal Mass, Damping and Stiffness and Scaled Mode Shapes

Recall that the assumed symmetry of H(s) along with the global nature of mode shapes implies that the residue matrix for each mode is proportional to $u_k u_k^t$. If $Qk = 2iA_k$, then equation (22) becomes

$$r_k = Q_k u_k u_k^t \qquad (n \times n) \tag{44}$$

Once a row or column of each residue matrix r_k has been identified, the mode shape vectors U_k can be calculated to within a constant of proportionality. This vector can be scaled large or small, if desired, by suitable choice of Q_k. Criteria for choosing Q_k will emerge from a discussion of modal mass, damping, and stiffness.

Consider a single degree of freedom system represented by

$$m\ddot{x} + c\dot{x} + k\dot{x} = f \tag{45}$$

where m, c, and k are scalars. The Laplace Transform gives

$$(ms^1 + cs + k)X(s) = F(s) \tag{46}$$

so that

$$H(s) = \frac{X(s)}{F(x)} = \frac{\frac{1}{m}}{s^2 + \frac{c}{m}s + \frac{k}{m}} \tag{47}$$

If the damping factor is less than one, the polynomial in the denominator can be factored.

$$H(s) = \frac{\frac{1}{m}}{(s-p)(s-p^*)} \tag{48}$$

where

$$p = \frac{-c}{2m} - \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}} \tag{49}$$

$$p = \frac{-c}{2m} + i\sqrt{\frac{k}{m} - \left(\frac{c}{2m}\right)^2} \tag{50}$$

$$p = -\sigma + i\omega, \quad \sigma > 0,\ \omega > 0 \tag{51}$$

and

$$p^* = -\sigma - i\omega \tag{52}$$

To express Equation (48) in the partial fraction form of Equation (39), solve for a and a^*.

$$H(s) = \frac{\frac{1}{m}}{(s-p)(s-p^*)} = \frac{a}{(s-p)} + \frac{a^*}{(s-p^*)} \tag{53}$$

$$\left.\frac{\frac{1}{m}}{(s-p^*)}\right|_{s=p} = \left[a + \frac{a^*(s-p)}{(s-p^*)}\right]_{s=p} \tag{54}$$

$$\frac{\frac{1}{m}}{2i\omega} = a \tag{55}$$

$$\frac{\frac{1}{m}}{-2i\omega} = a^* \tag{56}$$

$$H(s) = \frac{\frac{1}{m\omega}}{2i(s-p)} + \frac{\frac{1}{m\omega}}{2i(s-p^*)} \tag{57}$$

The residue r can be found from Equations (40), (41), and (57).

$$r = \frac{1}{m\omega} \tag{58}$$

Now note that Equations (50), (51), and (58) give m, c, and k in terms of r, ω, and σ.

$$m = \frac{1}{r\omega} \tag{59}$$

$$c = 2\sigma m \tag{60}$$

$$k = (\omega^2 + \sigma^2)m \tag{61}$$

For multiple degree of freedom systems, the analogous definitions are made for each mode k.

$$m_k = \frac{1}{Q_k \omega_k} \tag{62}$$

$$c_k = 2\sigma_k m_k \tag{63}$$

$$k_k = (\omega_k^2 + \sigma_k^2)m_k \tag{64}$$

Equations (44), (62), (63), and (64) are used to calculate modal mass, damping, and stiffness and scaled mode shapes in the Print Step. Q_k is arbitrary so it can be chosen to give unit mass, unit $u^t u$, etc.

The modal mass, stiffness, and damping coefficients can be interpreted as being the masses, dampers, and springs of decoupled, single degree of freedom systems. These systems are equivalent to the original system under a change of coordinates.

4. Measurement Implications of Modal Theory

A fundamental assumption of modal testing is that a mode of vibration can be excited from anywhere on an elastic structure, except of course along its node lines (zero points) where it can't be excited at all. This is another way of stating the result derived earlier (i.e., that the same modal vector--scaled by a different component of itself--is contained in every row and column of the transfer matrix). In addition, modal frequency and damping are constants which can be identified in any element of the transfer matrix, i.e., any transfer function taken from the structure.

It is important to recognize that this global mode shape concept exists within certain spatial boundaries, beyond which vibrations will not readily propagate. If two linear systems are completely isolated, then a single composite mode including both systems is not meaningful.

Conversely, it is important to include enough spatial points in the measured data set to describe all of the vibration modes of interest. If some region of a bounded system is not monitoried or excited, or if points are not chosen sufficiently close together, then some modes cannot be adequately represented.

When a system is represented by the partial fraction form of its transfer matrix, a closed form solution for the displacement at any point, for any combination of modes, is readily obtainable using simple matrix-vector multiplication. This is particularly helpful when the response is only to a few modes of interest.

The primary purpose for using modal coordinates to describe the dynamics of a linear vibration structure is that it drastically reduces the amount of time and effort necessary to measure the dynamics in a laboratory. The essence of the modal concept is that once one row or column of the transfer function matrix has been determined, the entire matrix and hence the entire dynamics of the structure can be specified.

In order to obtain valid modal results with the Modal Analysis system, several important assumptions of the modal theory described here must be satisfied.

1. The structure must exhibit the behavior of a linear system. If you are not able to successfully curve fit equation (14) to measured transfer function data, then the behavior may not be linear.

2. The structure must exhibit the reciprocity of symmetry property. This can be verified by comparing the transfer function obtained from an excitation measurement at point A and response measurement at point B with the transfer function obtained from an excitation at point B and response at point A. This should be the same.

3. The structure must have distinct pole pairs. Since the Modal Analysis system uses analytical expression (6) to perform the curve fitting, it cannot fit repeated poles (repeated roots of det(B) = 0 because this expression was derived under the assumption that the poles are unique. This condition can be difficult to detect in one set of transfer function measurements. To insure that the poles are unique you should measure a different row or column of the transfer function matrix, and compare the mode shapes from the two sets of measurements. If they are not identical there is a strong possibility of repeated roots.

4. There may be more than one modal vector corresponding to a given pole, due to certain kinds of boundary conditions on the structure, i.e., symmetric conditions along several axes. To insure that this is not happening, you should compare modal vectors obtained from two or more rows or columns of the transfer matrix.

5. The transfer function H(s) is defined in terms of an input force and a response displacement. Response velocity or acceleration can be converted to displacement. But non-force Modal Analysis system will calculate, print, and display modal data (i.e., poles and residues) for such measurements, however. The exceptions are the four mode shape scaling procedures that produce modal mass damping and stiffness. The system logica will reject an attempt to calculate these values, unless motion in response to force was measured.

V. PROCEDURE OF TEST CHAMBER CHARACTERIZATION

A. PROCEDURE OF DATA COLLECTION

After construction of the test chamber, preservation and painting, installation of cooling/heating coils, and installation of all insulation, the following is the procedure used for final characterization of the test chamber (with front panel removed).

1. Draw a 2.54 inch × 2.54 inch grid on entire inside surface of the test chamber. This grid is used to record location of impact or excitation, as well as location of response transducer (Figure 9).

2. Re-install exciter and support framework; re-install specimen fixture with specimen in place; and re-install test chamber top. Drill 1/4 inch hole through specimen for attachment of exciter driver rod. Install exciter driver rod with Force Transducer in place (Figure 10). NOTE: Acoustic exciter and force transducer will not be used in this work. For impulse hammer testing disconnect exciter from specimen.

3. Using accelerometer mounting wax, attach pick-up transducer to desired location. Connect signal conditioners and wiring as instructed in the operating manuals. System flow chart is presented in Figure 11. Impulse hammer, signal conditioners and typical attachment of pickup transducer are

Figure 9. Detail of 10 cm × 10 cm grid on inside of experiment test chamber

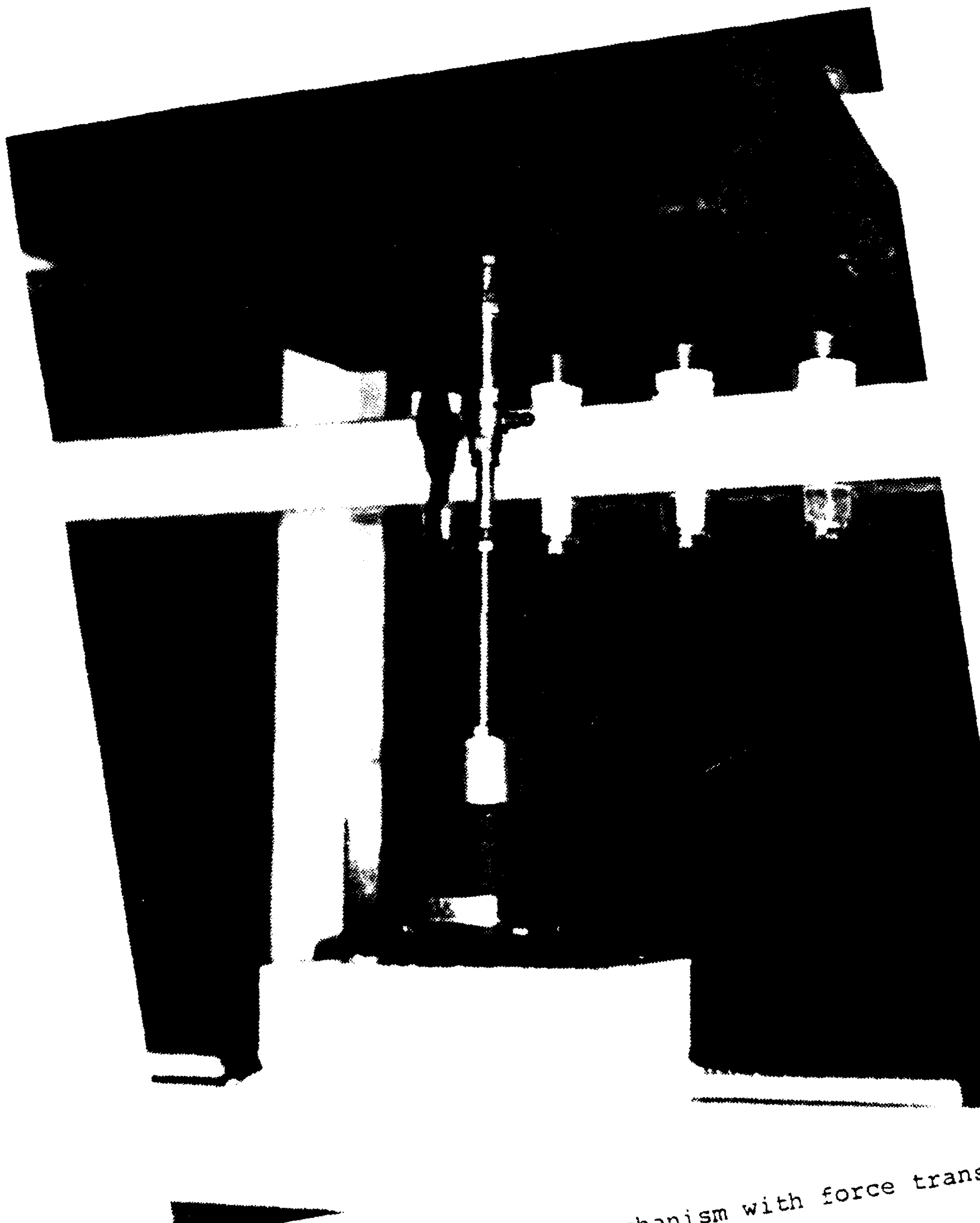


Figure 10. Exciter drive mechanism with force transducer

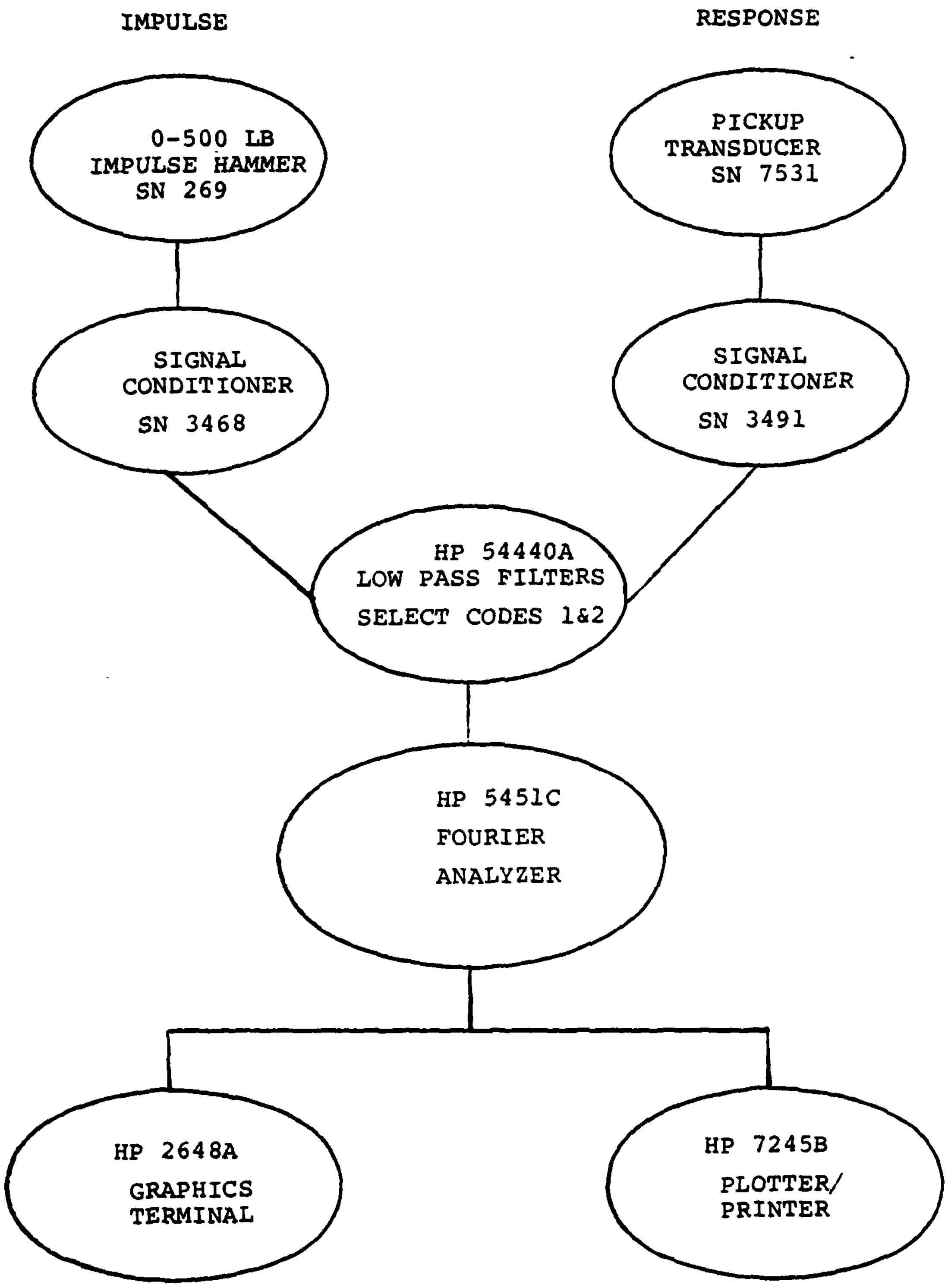


Figure 11. Impulse hammer technique flow chart

presented in Figures 12 and 13. All calibration data of sensors and mounting and instructions are included in Appendix C.

4. Turn on the HP-5451C Fourier Analyzer (HP-2648A Graphics Terminal will automatically be energized). Insert "Modal" disk into disk drive. Energize disk drive. When "Disk Ready" light comes on "Boot" the system as outlined in volume 1 of System Operating Manual (Figures 14 and 15). Activate user assignable keys f1 and f2 on the graphics terminal to "Graphics Mode" and "Alpha Mode" respectively. Procedures for key assignments are found in volume 5 of the Computer Operating Manual.

5. From this point on, the procedure for taking impulse data is interactive. Locally generated computer programs, which are designed to allow the data generated by impulse hammer technique to be stored and later processed by the off-line Modal software, are presented in Appendix D. What follows is a typical step-by-step impulse data taking session assuming pick-up transducer at location L051 and hammer impulse location at L066 The following abbreviations will be used:

   C = computer keyboard entry

   D = graphics terminal display

   G = graphics terminal entry

   R = user response

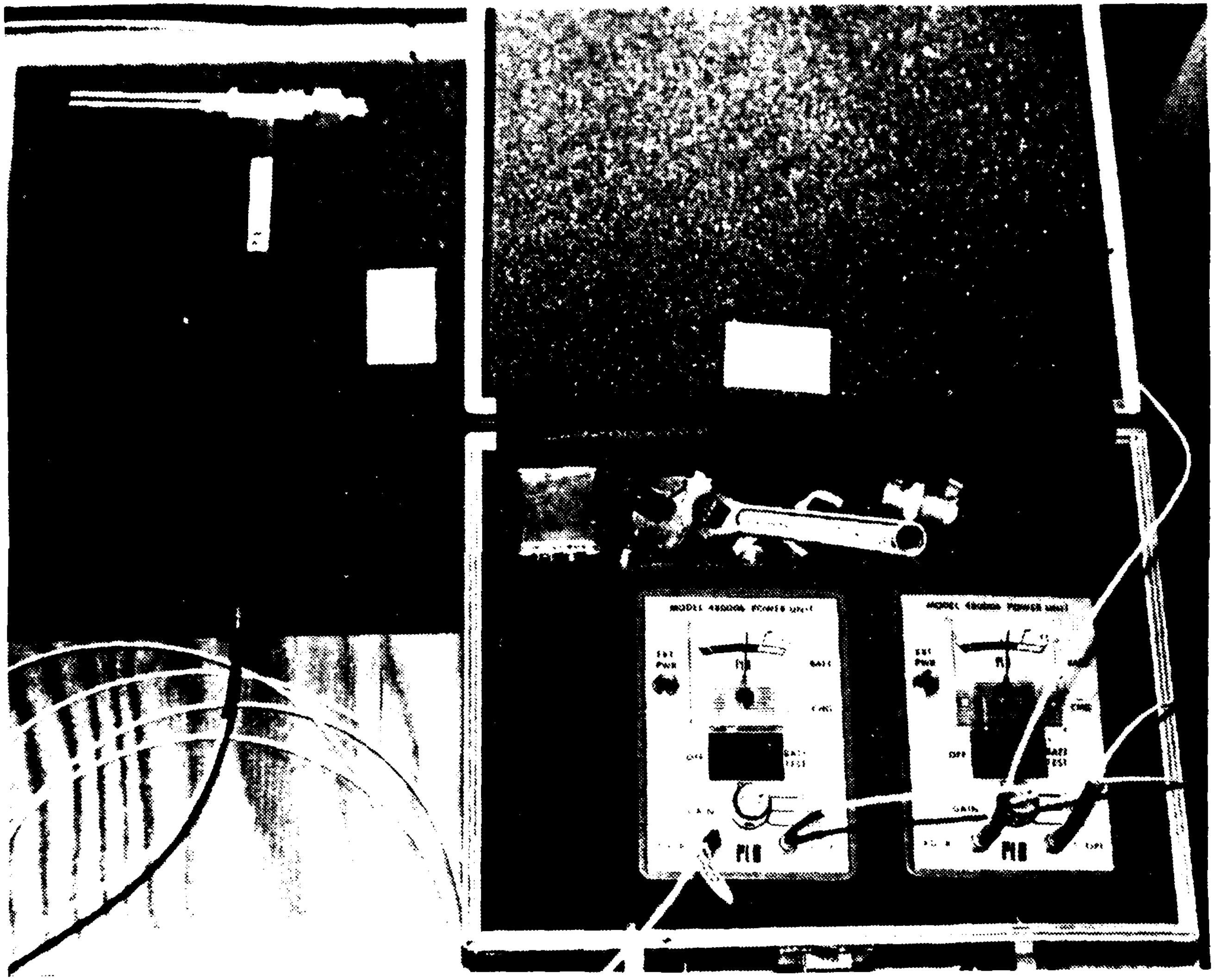


Figure 12. Impulse hammer with signal conditioners

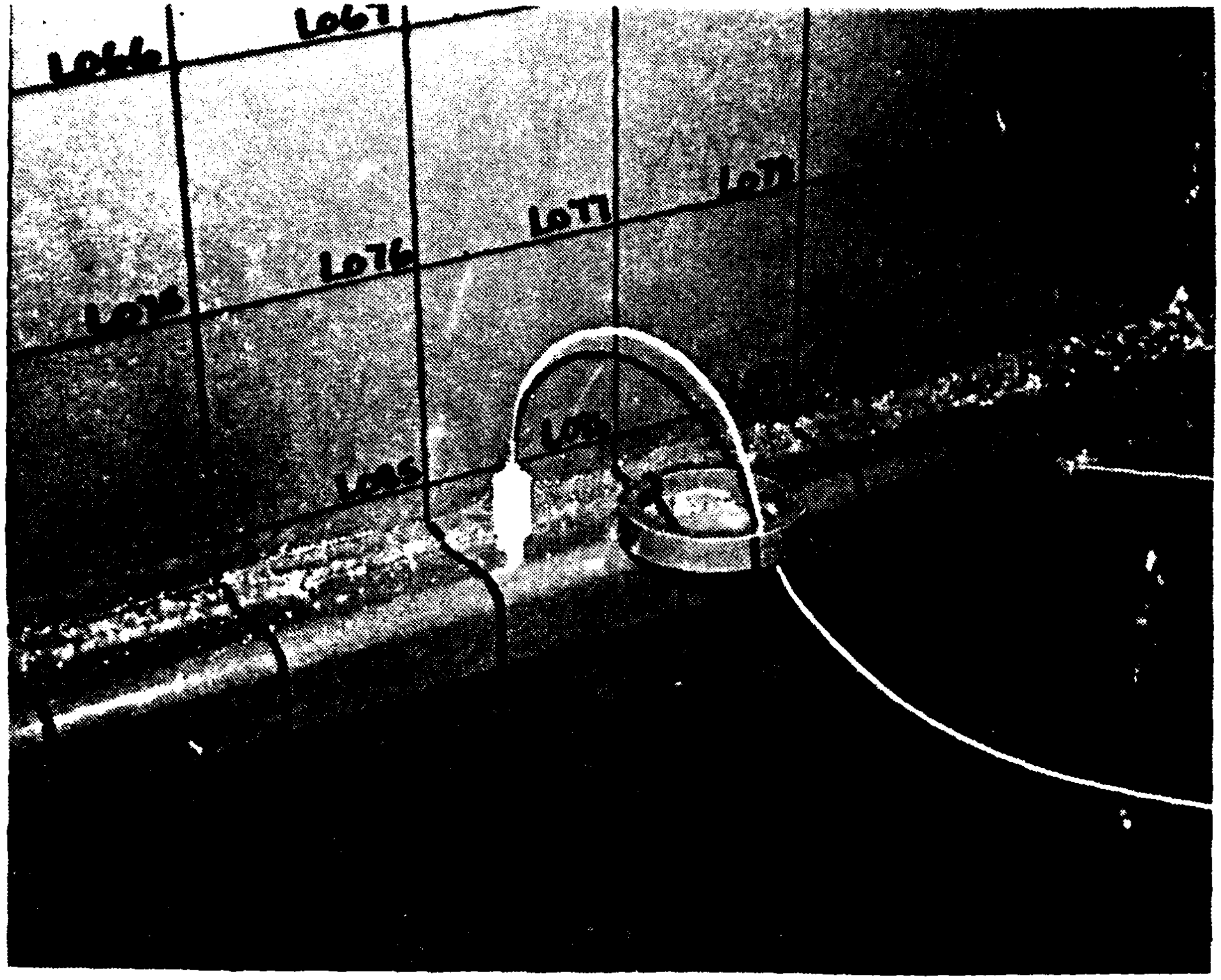


Figure 13. Typical attachment of pick-up transducer

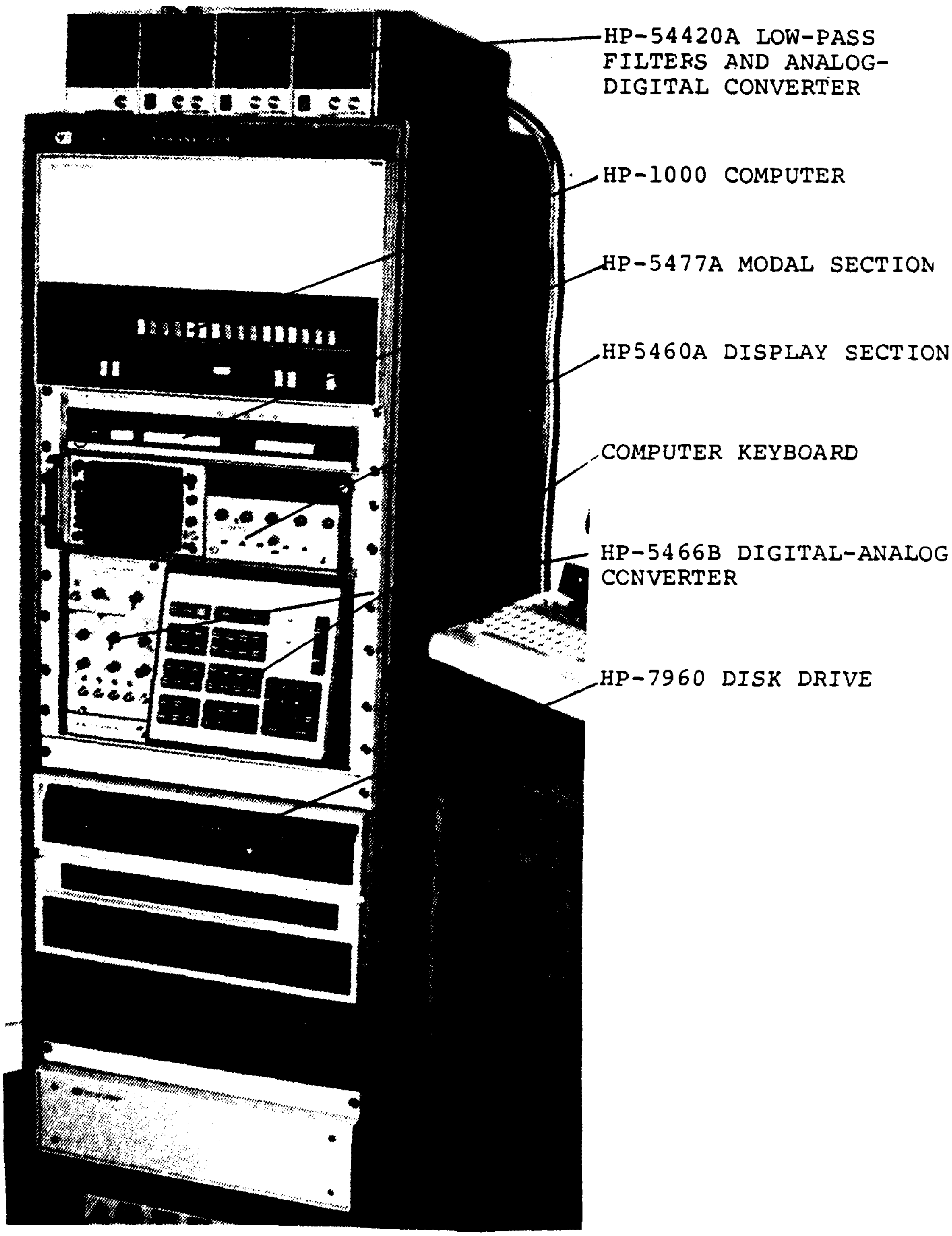


Figure 14. HP-5451C Fourier Analyzer

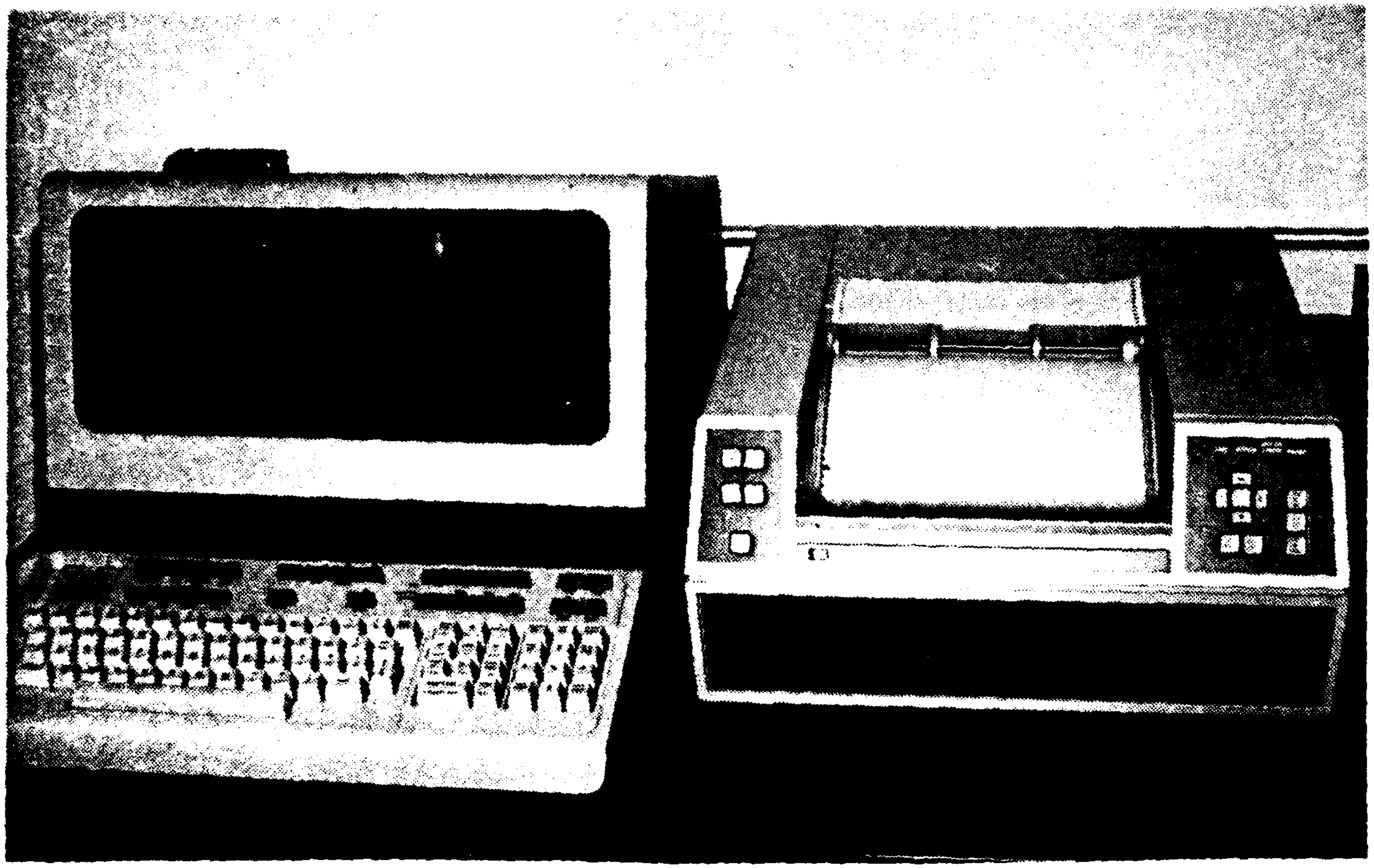


Figure 15. HP-2648A Graphics Terminal and HP-7245B Printer/Plotter

Step Number

1. Normal "Boot" of modal with f1 & f2 programmed.
2. D: SET UP DATA NUMBER? (1 to 5).
3. R;C: 2 [ENTER] (want to preserve Demonstration data in set up #1, set ups #2 through #5 are available).
4. D: LIST(1), EDIT(2), FINISH(3)?
5. R;C: 2 [ENTER] (must enter particular transducer specifications and general information for a particular test).
6. D: LABEL?
7. R;G: TANK CHARACTERIZATION [RETURN] (title of particular test).
8. D: LINE NOS.? (FIRST,LAST).
9. R;G: 1,6 [RETURN] (you may modify one or any sequential series of lines of the set up data).
10. D: 1. NO. OF MEASUREMENTS?
11. R;G: 16 [RETURN] (A measurement is one record of storage on the disk. One record is 1024 words in length, and a test is n measurements stored in n contiguous records on the disk).
12. D: STARTING LOCATION OF MEAS. STORAGE (1 to 485).
13. R;G: 5 [RETURN] (storage location 1 through 255 are on the removable disk, and storage locations 266 to 485 are on the fixed disk).
14. D: DATA BLOCK SIZE? (64 to 2048).
15. R;G: 1024 [RETURN] (block size of 1024 will give maximum zoom capability).

16. D: 4. POLAR TRANS. FUNCT. DISPLAY? LINEAR(1) or LOG(2) MAGNITUDE.

17. R;G: 2 [RETURN].

18. D: 5. TRANSDUCER UNITS? ENGLISH(1), METRIC(2).

19. R;G: 1 [RETURN].

20. D: TRANSDUCER SCALE FACTORS (VALUE,UNITS)

    1 = MV/G, 2 = VM/IPS, 3 = MV/IN, 4 = MV/LB

    A. INPUT?

21. R;G: 10.6,4 [RETURN] (values are obtained from calibration data of sensors).

22. D: B. RESPONSE?

23. R;G: 10.12,4 [RETURN].

24. D: G. AMPLIFIER GAINS?

    A. INPUT?

25. R;G: 1 [RETURN] (enter transducer amplifier switch setting).

26. D: B. RESPONSE?

27. R;G: 1 [RETURN]

28. D: LIST(1), EDIT(2), FINISH(3)?

NOTE: At this point (1) may be entered and all data may be checked. If any corrections are required, enter (2) and use procedures outlined in steps 5 through 27.

29. R;G: 3 [RETURN].

NOTE: The "set up" portion of the test is now complete. The next step is the "measure" portion.

30. D: STEP NUMBER? (1 to 5).

31. R;C: 2 [ENTER] (the computer is now in the "measure" mode).

32. D: TRANS(1), RANDOM(2), DISK(3), USER(4), FOURIER/ZOOM/GRAPHICS(5)?

33. R;C: 5 [ENTER] (the HP 5451-C is now ready to set up for an impulse test).

34. R;C: SELECT BLOCK SIZE (1024 MAX FOR ZOOM)
SET ADC FREQUENCY RANGE AS DESIRED
SET TREGGER TO INTERNAL

35. R;C: [JUMP] 0 [SPACE] 1 [ENTER] (this command calls the user programs 1,50,51,52, and 59 for use).
TRANSFER FUNCTION MEASUREMENTS
ARE HP FILTERS INSTALLED?

36. D: (0 = NO 1 = YES)

37. R;C: 1 [ENTER]

38. D: CUT-OFF FREQUENCY (CHANNEL NO)?

NOTE: To eliminate unwanted or meaningless data beyond range of impulse hammer, enter channel number above which the computer will not sampel data.

EXAMPLE: 0-500 lb. hammer useful range is from 0-6000 Hz, with block size 1024 selected channels above 307 are meaningless.

39. R;C: 307 [ENTER]

40. D: IMPACT (1) OR RANDOM (2) EXCITATION?

41. R;C: 1 [ENTER]

42. D: NO. OF AVERAGES?

43. R;C: 4 [ENTER]

44. D: BASEBAND OR ZOOM MEASUREMENT?

(0 = BASEBAND 1 = ZOOM)

45. R;C: 0 [ENTER] (first measurement must be baseband).

46. D: BASEBAND IMPACT MEASUREMENT

PRESS CONTINUE FOR MEASUREMENT

NOTE: At this point trigger and analog-Digital Converter levels need to be set to do this. The following keg strodes should be done.

47. R;C: SET REPEAT/SINGLE SWITCH TO REPEAT

PRESS ANALOG IN

SET ADC RANGE SWITCHES AND TRIGGER SLOPE AND LEVEL

SET ADC TO SINGLE WHEN READY AND PRESS CONTINUE

48. R;C: [CONTINUE].

NOTE: Impact 4 times. The computer will beep after each data entry. After the computer processes the data the ready light will come on and the data in Block 0 will be displayed on the small screen of the computer. Processed data are stored in the following locations and can be displayed by the key strokes:

[DISPLAY] 0 [ENTER] Log transfer function

[DISPLAY] 1 [ENTER] Coherence

[DISPLAY] 2 [ENTER] Input power spectrum

[DISPLAY] 3 [ENTER] Output power spectrum

[DISPLAY] 4 [ENTER] Cross power spectrum

[DISPLAY] 5 [ENTER] Raw data

To obtain hard copy of any of the above outputs execute the following key commands [USER[5821 [SPACE] 35 [ENTER]. Then enter [USER] [PLOT] [ENTER]. To return plotting to graphics execute [USER] 5821 [SPACE] 6 [ENTER], and when the Graphics Terminal is in the Graphics mode (depress f1) and [USER] [PLOT] [ENTER] is executed all plotting to be sent to the graphics terminal. To continue, f2 must be depressed. After all preliminary graphing is completed on baseband data press [continue]. Typical plots of baseband data are presented in Figures 16 through 20.

49. D: PRESS CONTINUE WHEN READY

50. R;C: [CONTINUE]

51. D: SAVE DATA?
    (0 = NO 1 = YES)

52. R;C: 0[ENTER]

53. D: MAKE ANOTHER MEASUREMENT?
    () = NO 1 = YES).

54. R;C: 1[ENTER]

55. D: NO. OF AVERAGES?

56. R;C: R[ENTER]

57. D: BASEBAND OR ZOOM MEASUREMENT?
    () = BASEBAND 1 = ZOOM)

58. R;C: 1[ENTER]

59. D: ZOOM IMPACT MEASUREMENT
    MOVE CURSOR TO START FREQUENCY
    PRESS "VALUE" (SWITCH REGISTER 11)

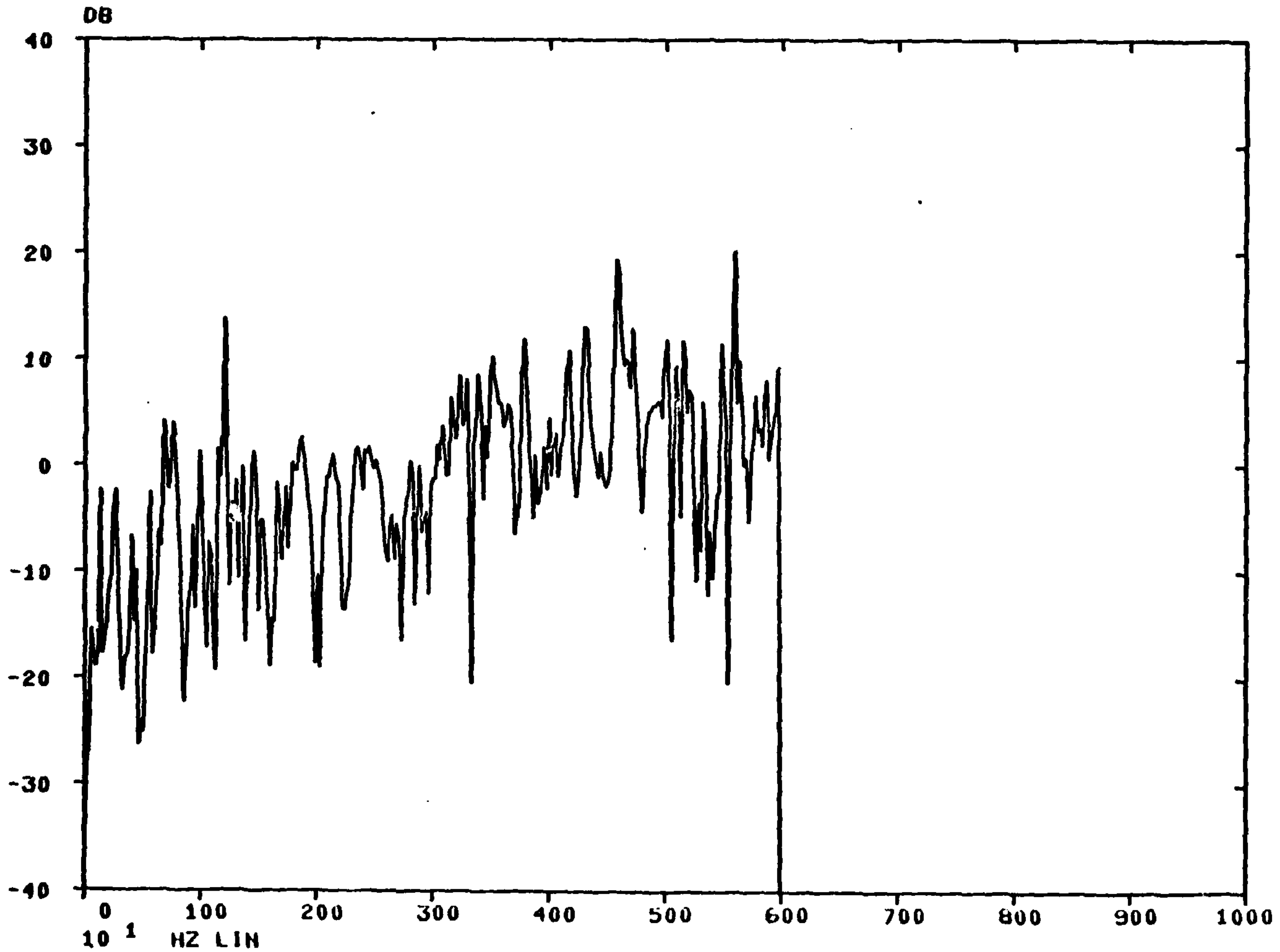


Figure 16. Log of transfer function of baseband data

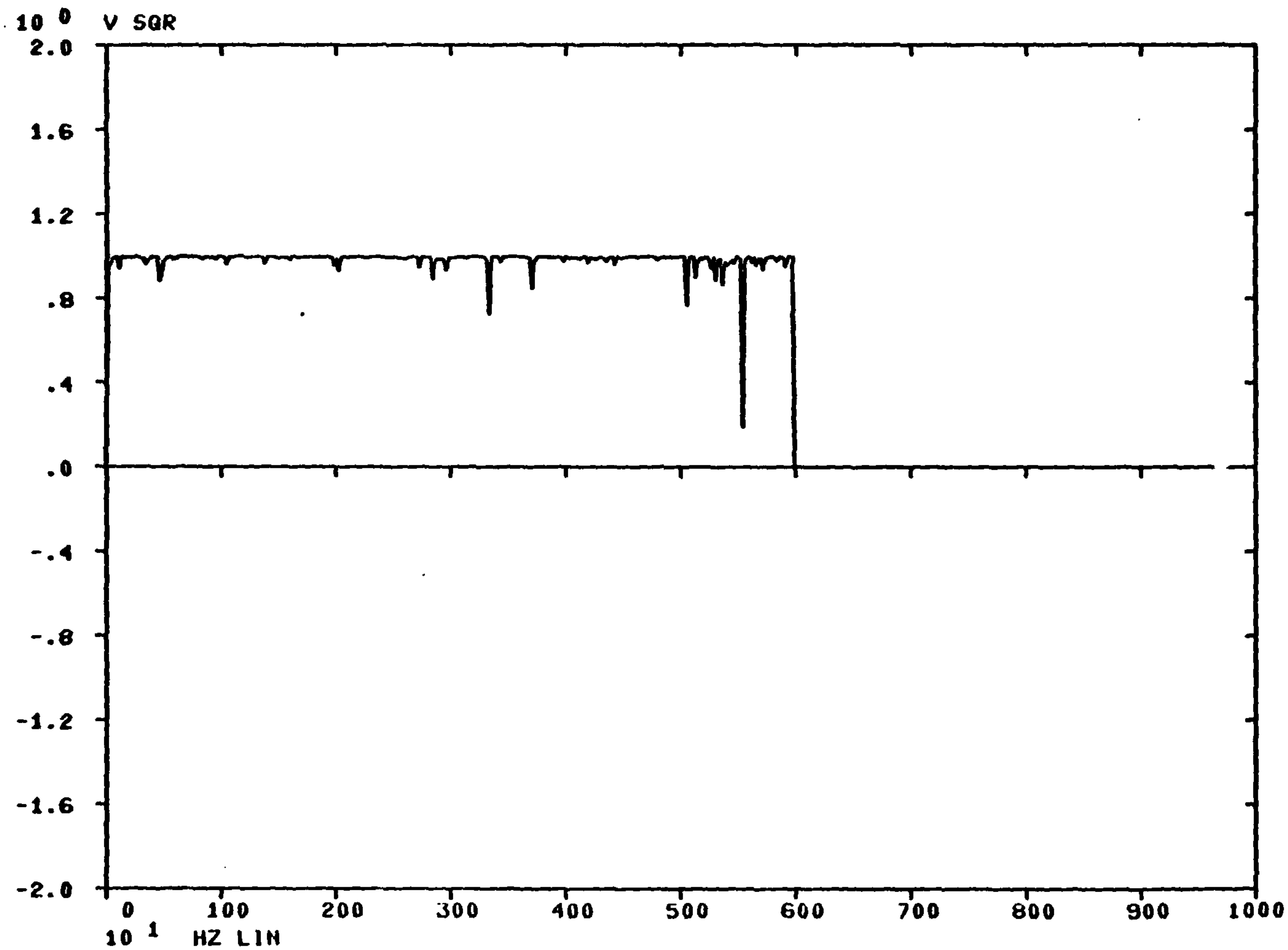


Figure 17. Coherence of baseband data

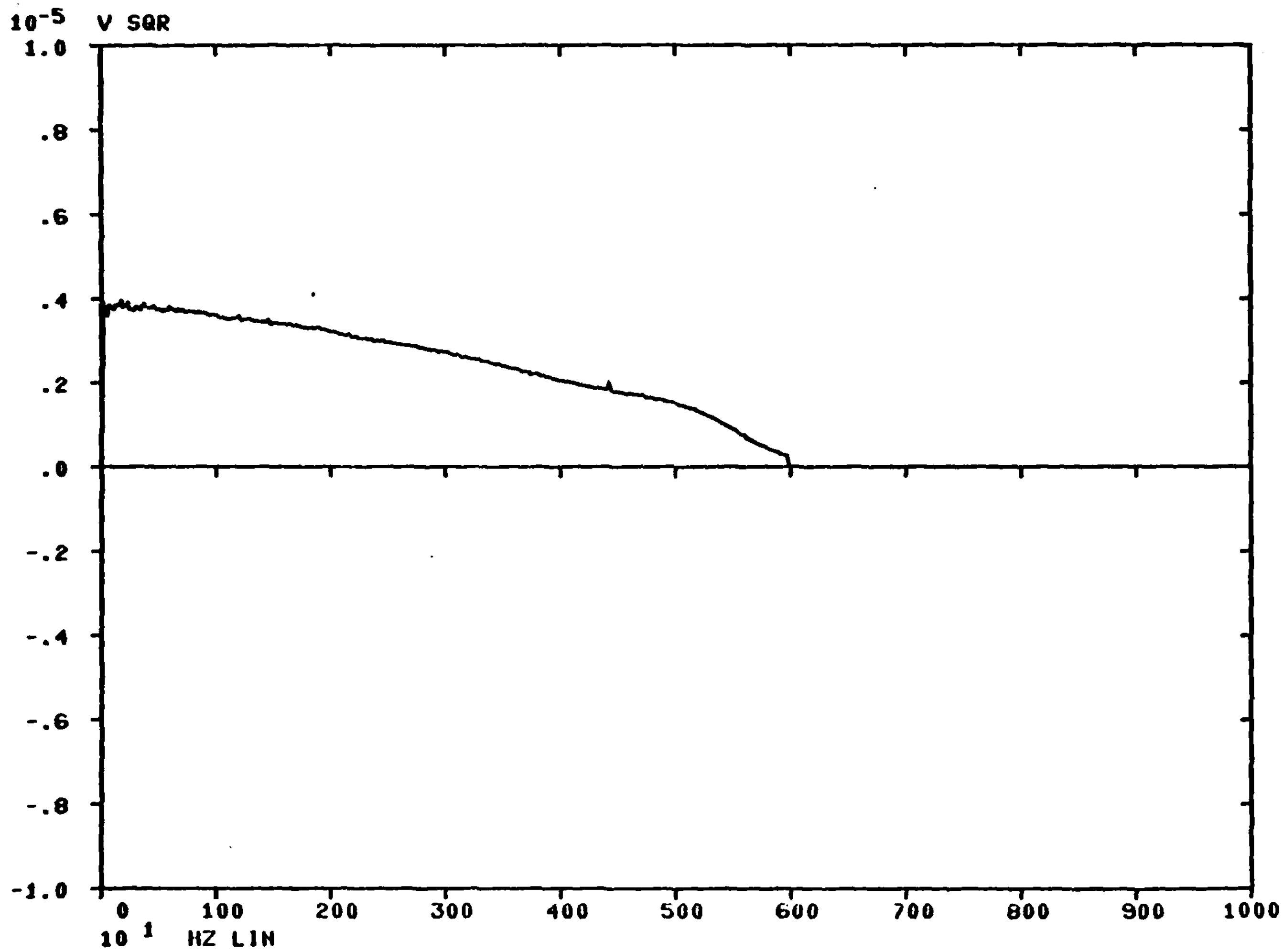


Figure 18. Input power spectrum of baseband data

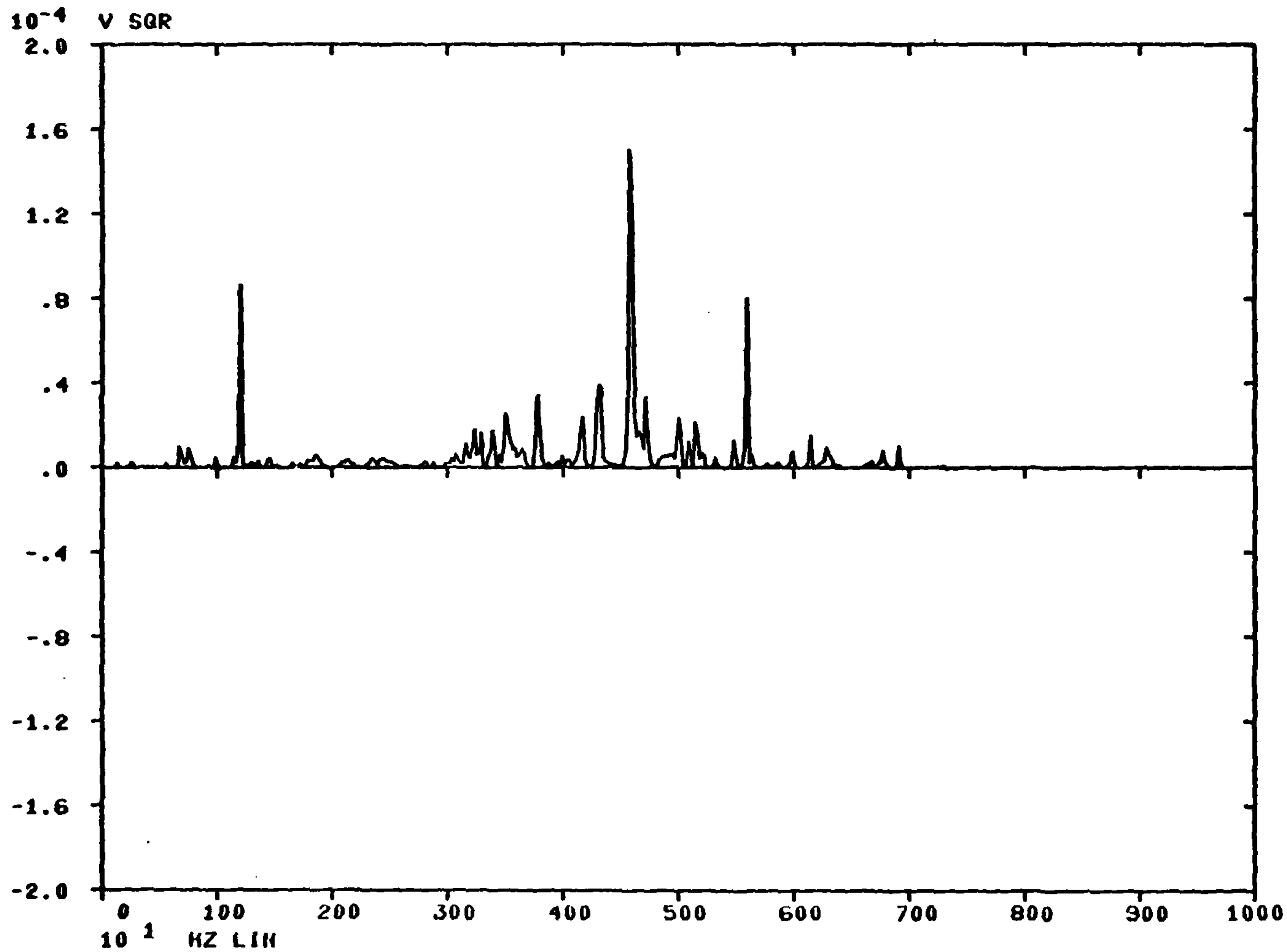


Figure 19. Output power spectrum of baseband data

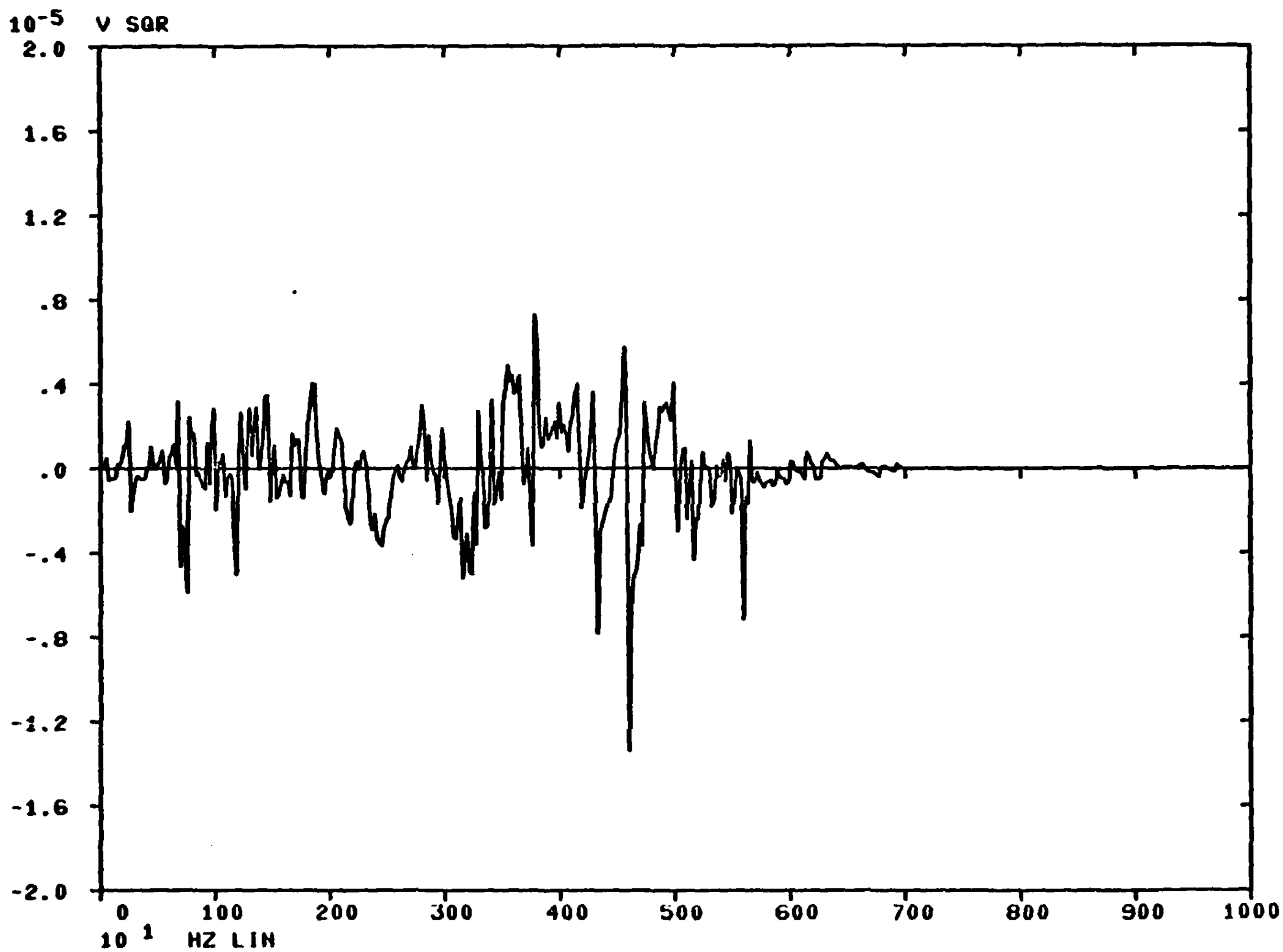


Figure 20. Cross power spectrum of baseband data

NOTE: The desired start and end frequency for the zoom measurement is not entered with use of cursor.

60. D: "TYPICAL" ZOOM IMPACT MEASUREMENT

MOVE CURSOR TO START FREQUENCY

PRESS "VALUE" (SWITCH REGISTER 11)

CHANNEL = 49.0000

FREQUENCY = 957.0999 HZ

AMPLITUDE = -700.0026 E -9.0000

MOVE CURSOR TO END FREQUENCY

PRESS "VALUE"

61. D: CHANNEL = 134.0000

FREQUENCY = 2618.0000 HZ

AMPLITUDE = -381.7491 E -9.0000

ANALYZE OLD OR NEW DATA?

1 = OLD (FROM THROUGHPUT FILE)

2 = NEW (WILL WRITE TO THROUGHPUT FILE)

PRESS CONTINUE FOR MEASUREMENT

62. R;C: 2 [ENTER]

NOTE: Whenever zoom is being done new data is required.

63. R;C: [CONTINUE]

NOTE: For zoom measurement the impact should be a series of rapid impacts with a varying interval between impacts. The trigger light will remain lit thorughout the data taking session.

64. D: ANALYZING THROUGHPUT DATA "TYPICAL"

CNTR FREQ 1479 HZ/DIV 125.0

DF: 000.2441406 BLOCKS LEFT 25

ZOOM POWER 4

NOTE: After data has been analyzed and desired plots made as described in step 43, ZOOM data should be stored for later use by the off-line modal software. A recommended data sheet is shown in Figure 21. It is important to log number of measurements and start location of measurement storage.

65. D: PRESS CONTINUE WHEN READY

NOTE: Generally it is desired to make multiple tests at different locations at the same frequency range so that a modal analysis can be done at a later time.

66. R;C: [CONTINUE]

67. D: SAVE DATA?

(0 = No 1 = YES)

NOTE: The data taking session can be repeated by entering "0".

68. R;C: 1[ENTER]

69. D: DATA STORAGE NO.?

70. R;C: XXX[ENTER]

NOTE: Data storage registers 0 through 500 are available for permanent storage of the data.

71. D: MAKE ANOTHER MEASUREMENT?

(0 = NO 1 = YES)

NOTE: From this point the steps 57 through 71 will be repeated for as many zoom measurements as desired. Each zoom measurement will be stored in a next higher record number with the begin record number known.

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)

Figure 21. Sample data sheet

After all data has been taken and recorded, and the number of measurements and start record measurement has been correctly entered in the set-up table, the system is ready to proceed.

72. R;C: [SELECT STEP] Modal Analysis Controller

73. D: STEP NUMBER?

74. R;C: [X] [ENTER] where X = set up
data number i.e.,
1 for example

75. D: LIST(1), EDIT(2), FINISH(3)?

76. R;C: 3[ENTER] assuming all data correct.

From this point on, the procedure for the mode identification and damping measurement is covered in Reference 6. For the tank characterization the modes identified and damping measured at the particular modes are presented in Table II.

B. TEST CHAMBER MAJOR MODES AND DAMPING

To identify the major modes and measure the damping of the test chamber the polar plot of the baseband band was divided into 10 sections (Figure 22), and each section was zoomed using the same pickup location and using the same impact location on left, right, deck and back panel.

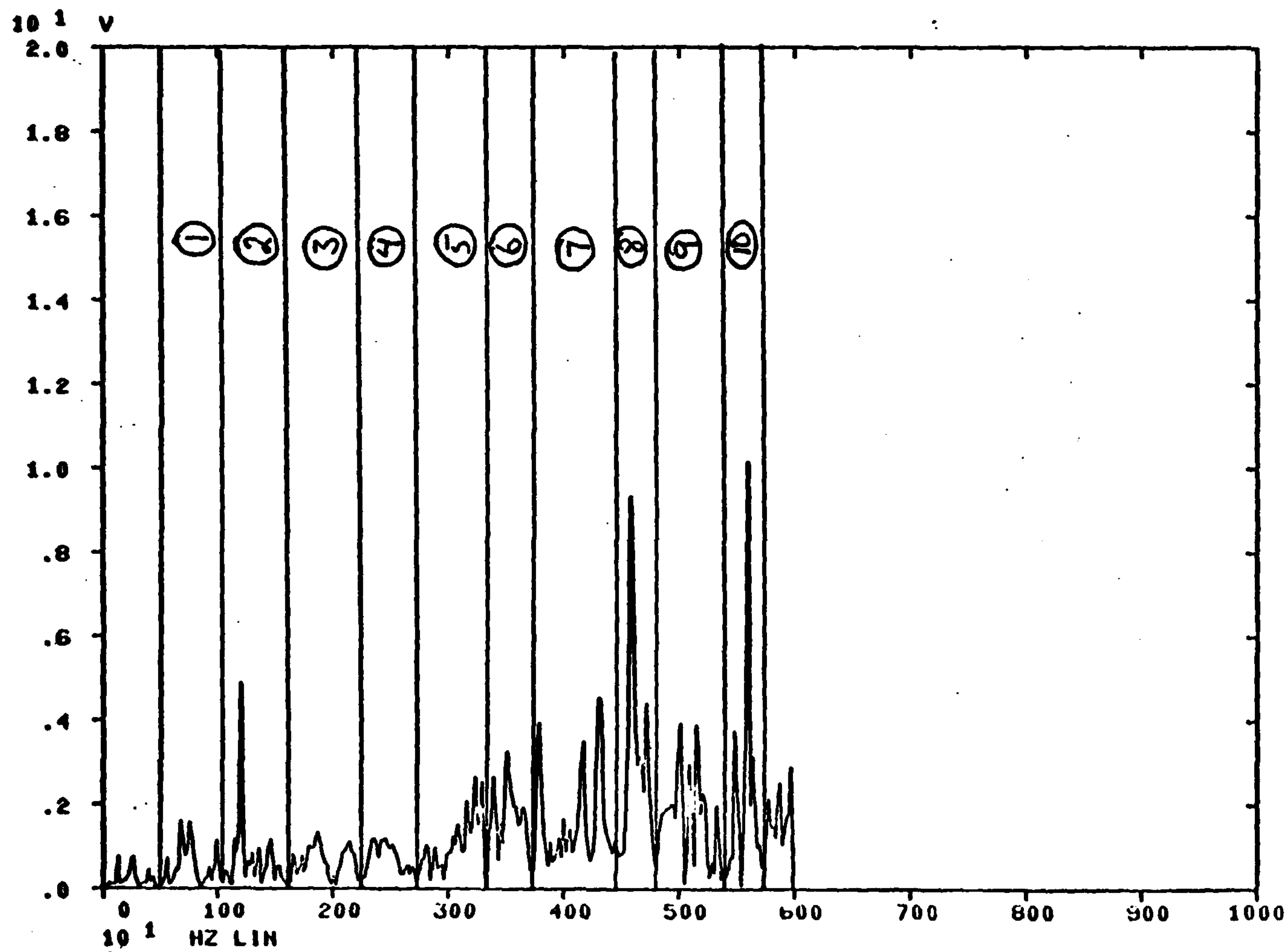


Figure 22. Polar presentation of transfer function for baseband of the test chamber

TABLE I

TEST CHAMBER FREQUENCY SECTIONS

SECTION NO.	START FREQ. (Hz)	STOP FREQ. (Hz)	CNTR. FREQ. (Hz)	DELTA FREQ. (Hz)
1	423	1,138	781	1.395
2	976	1,471	1,221	0.977
3	1,583	2,247	1,780	1.786
4	2,247	2,715	2,481	1.221
5	2,735	3,321	3,028	1.627
6	3,340	3,711	3,525	0.977
7	3,711	4,493	4,102	1.953
8	4,473	4,805	4,639	0.814
9	4,805	5,411	5,108	1.630
10	5,411	5,723	5,567	0.814

A modal analysis of each section was completed. Major modes and damping for each major mode was analyzed. The results are presented in Table II. Test data are included in Appendix E.

TABLE II

TEST CHAMBER MODES AND DAMPING FACTORS

SECTION NO.	NO. OF MODES	AVERAGE DAMPING FACTORS (%)	STANDARD DEVIATION OF DAMPING
1	3	0.5895	0.3059
2	2	0.3642	0.0035
3	10	0.8918	0.2458
4	12	0.7375	0.5084
5	10	0.3601	0.1934
6	6	0.2763	0.1065
7	8	0.3115	0.2176
8	3	0.2219	0.0627
9	10	0.1787	0.0873
10	2	0.1660	0.0525

The overall average damping factor of the test chamber is 0.4667% with an overall standard deviation of 0.3689%.

VI. PROCEDURE FOR DAMPING MEASUREMENT OF SPECIMEN

A. SPECIMEN SECURED IN FIXTURE INSIDE TEST CHAMBER

The test specimen (cast nickel-aluminum bronze, code FTC) was secured in the test chamber, impact locations A, B, C, are shown in Figure 23. To identify the major modes and measure the damping factor of the specimen the 0 to 500 lb. impulse hammer was used for the frequency range up to approximately 6000 Hz, and the 0 to 50 lb. impulse hammer was used for the frequency range from approximately 5000 Hz to approximately 12,000 Hz. Baseband polar plots for each impulse hammer at each location are shown in Figures 24 through 29. It should be noted that there is very good correlation between the 0-500 lb. impulse hammer and the 0-50 lb. impulse hammer. Additionally, there is very good correlation between various impact locations.

Utilizing the baseband data (0-500 lb. impulse hammer), obtained for impact location B, five frequency ranges were investigated. Additionally, using the baseband data obtained from the 0-50 lb. impulse hammer at location B, the frequency ranges of three additional ranges were investigated. Specimen Frequency sections are listed in Table III. Specimen modes and damping factors are presented in Table IV. Measurement data and rough log sheets are included in Appendix F.

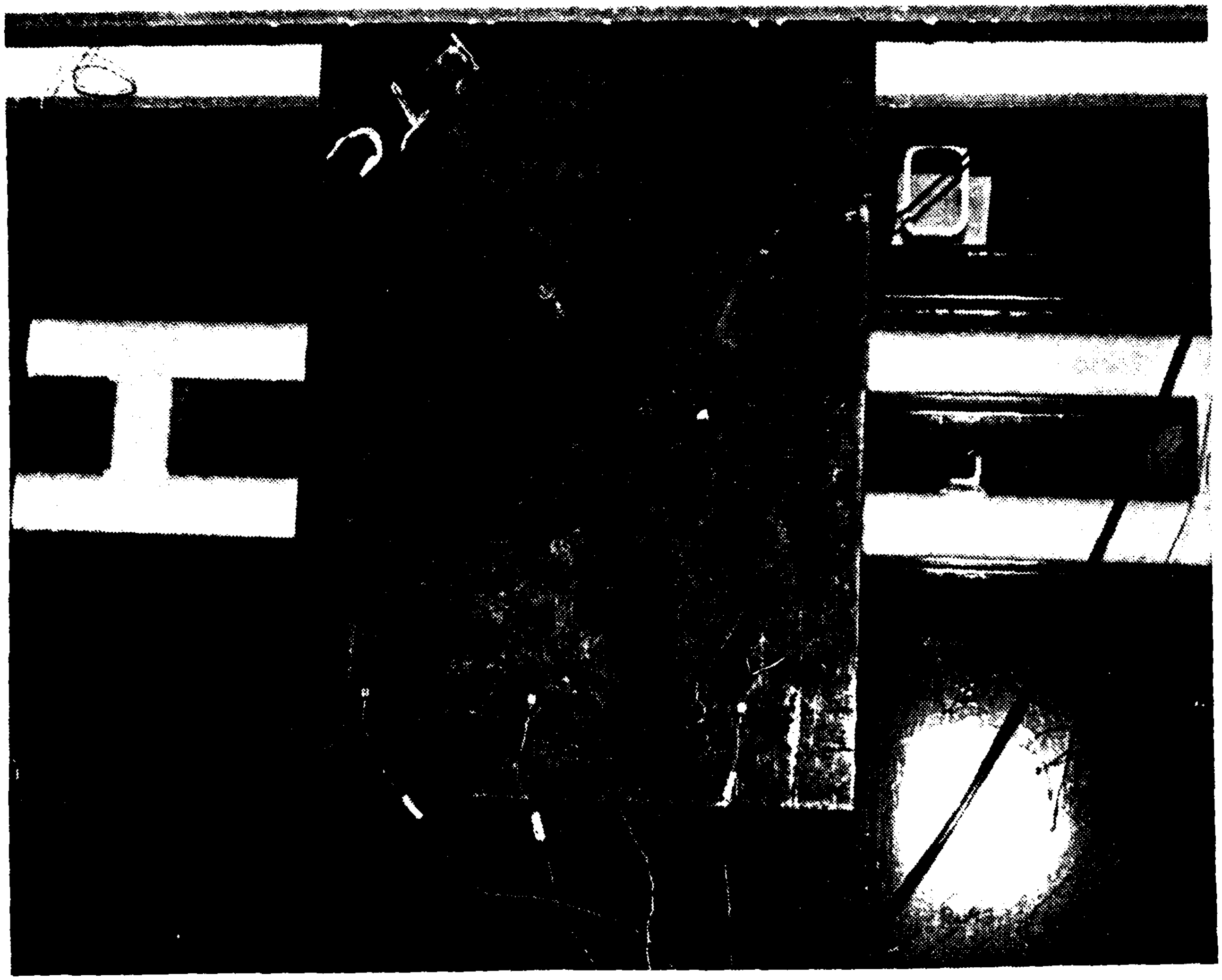
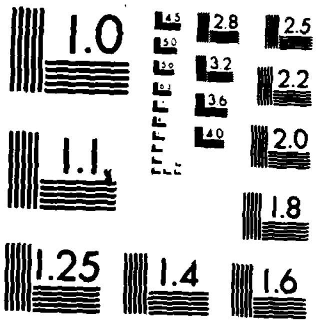


Figure 23. Cast nickel-aluminum bronze, code FTC specimen secured in the test chamber with impact locations identified

AD-A132 701 THE DESIGN OF A TEST PROCEDURE FOR THE MEASUREMENT OF ACOUSTIC DAMPING OF MATERIALS AT LOW STRESS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R A HEIDGERKEN SEP 83

2/3

UNCLASSIFIED F/G 17/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

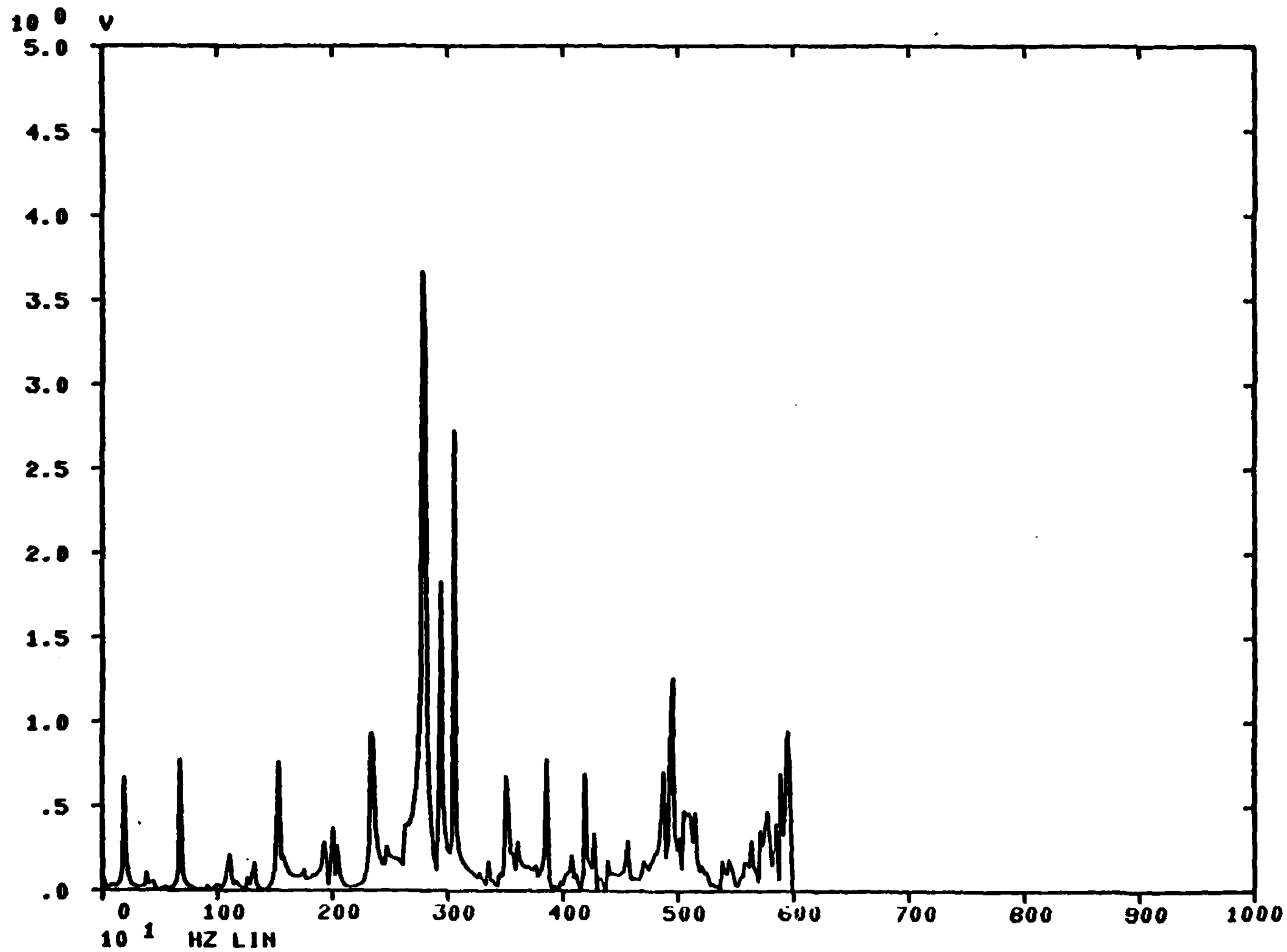


Figure 24. Polar presentation of transfer function for baseband (0-500 lb. impulse hammer). Impact location A

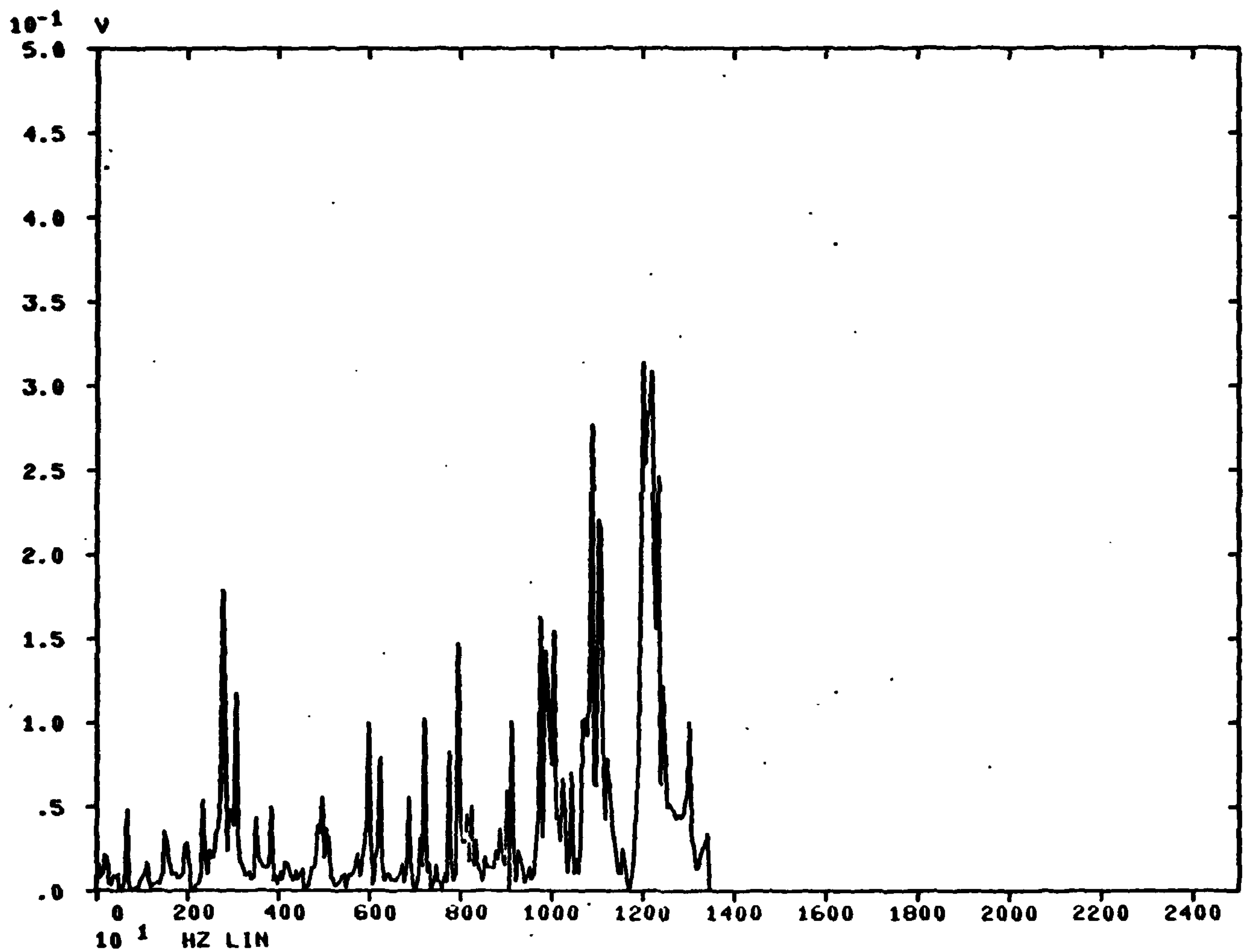


Figure 25. Polar presentation of transfer function for baseband (0-50 lb. impulse hammer). Impact location A

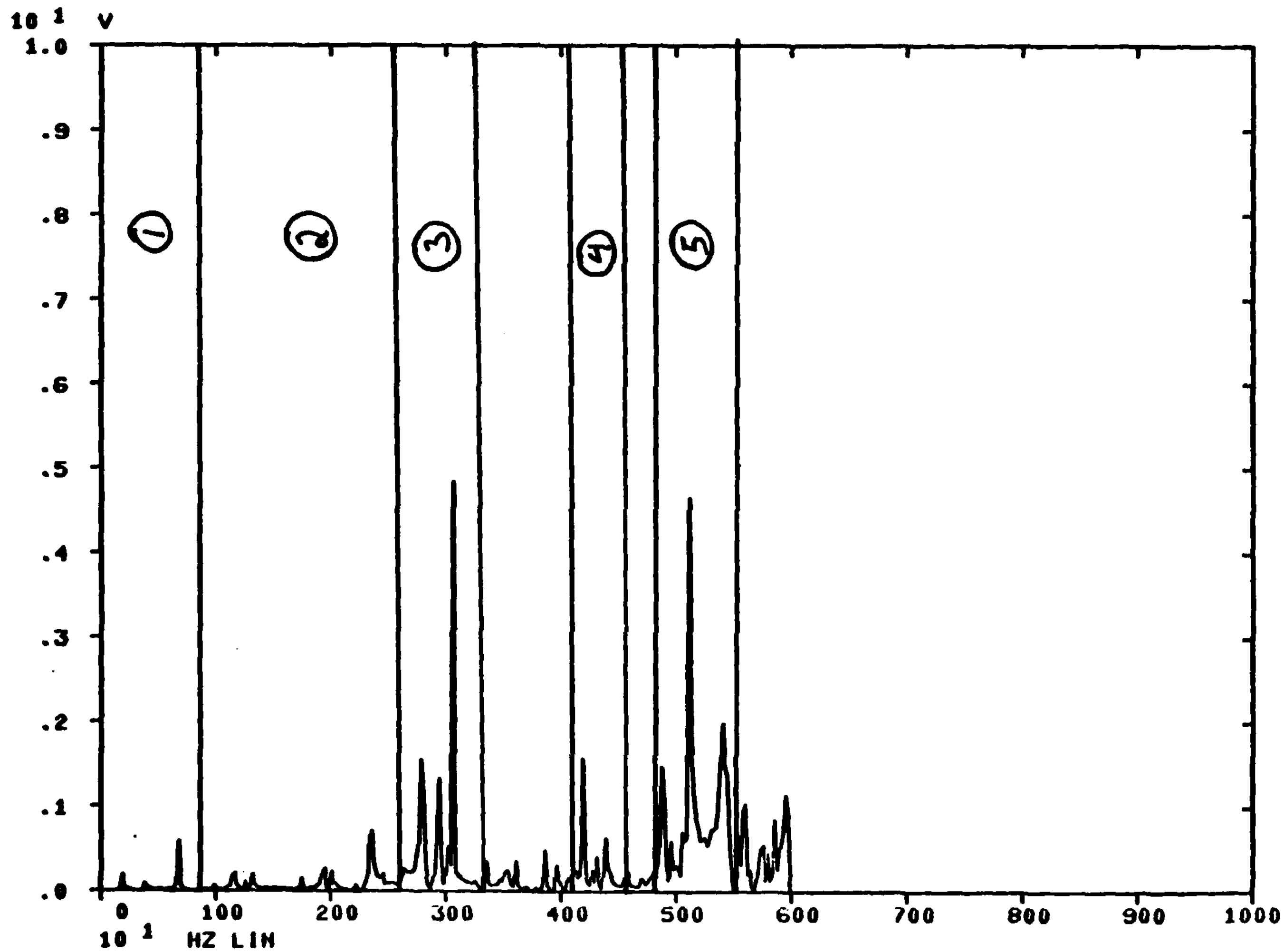


Figure 26. Polar presentation of transfer function for baseband measurement (0-500 lb. impulse hammer). Impact location B. Zoom ranges identified

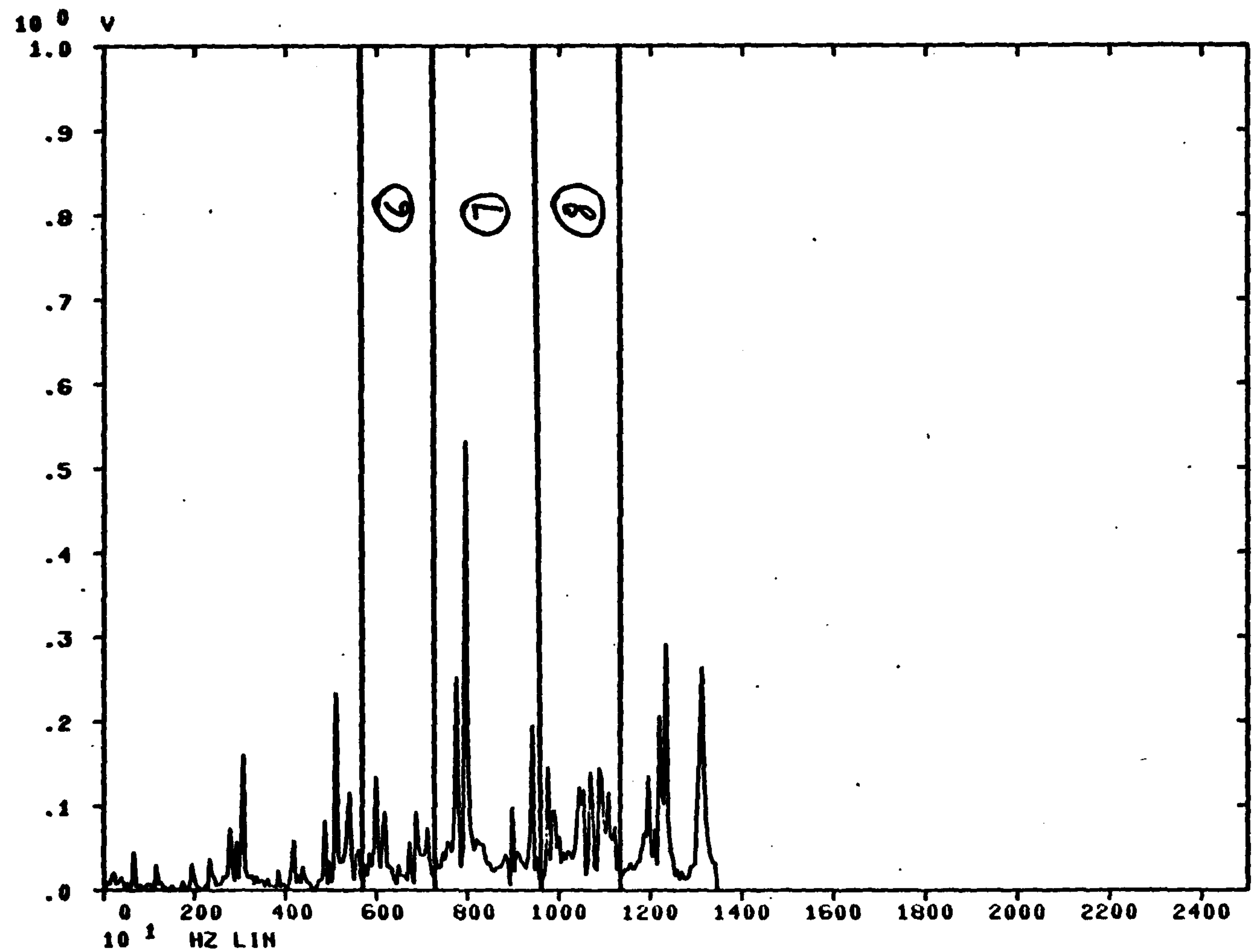


Figure 27. Polar presentation of transfer function for baseband measurement (0-50 lb. impulse hammer). Impact location B. Zoom ranges identified

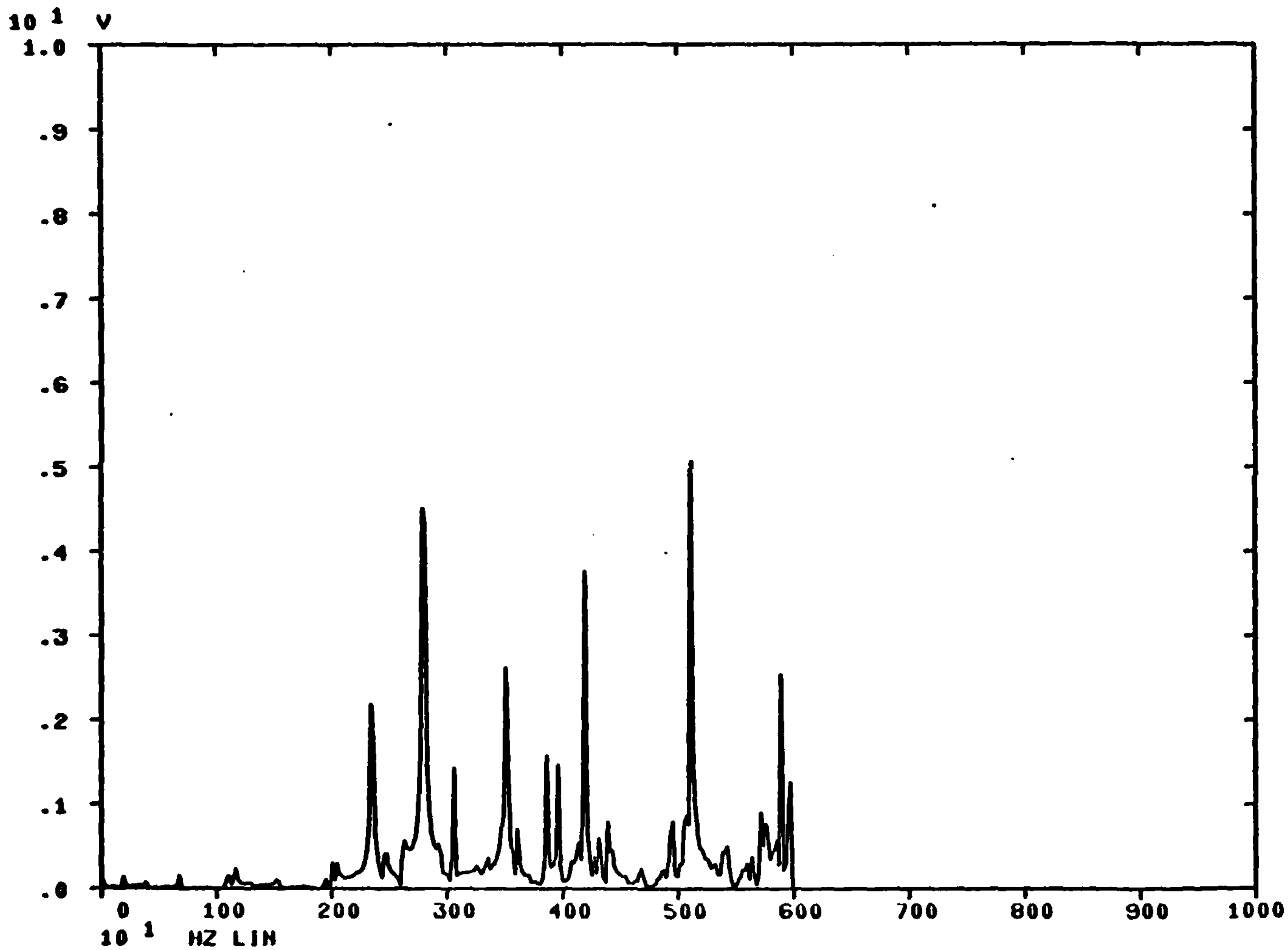


Figure 28. Polar presentation of transfer function for baseband measurement (0-500 lb. impulse hammer). Impact location C

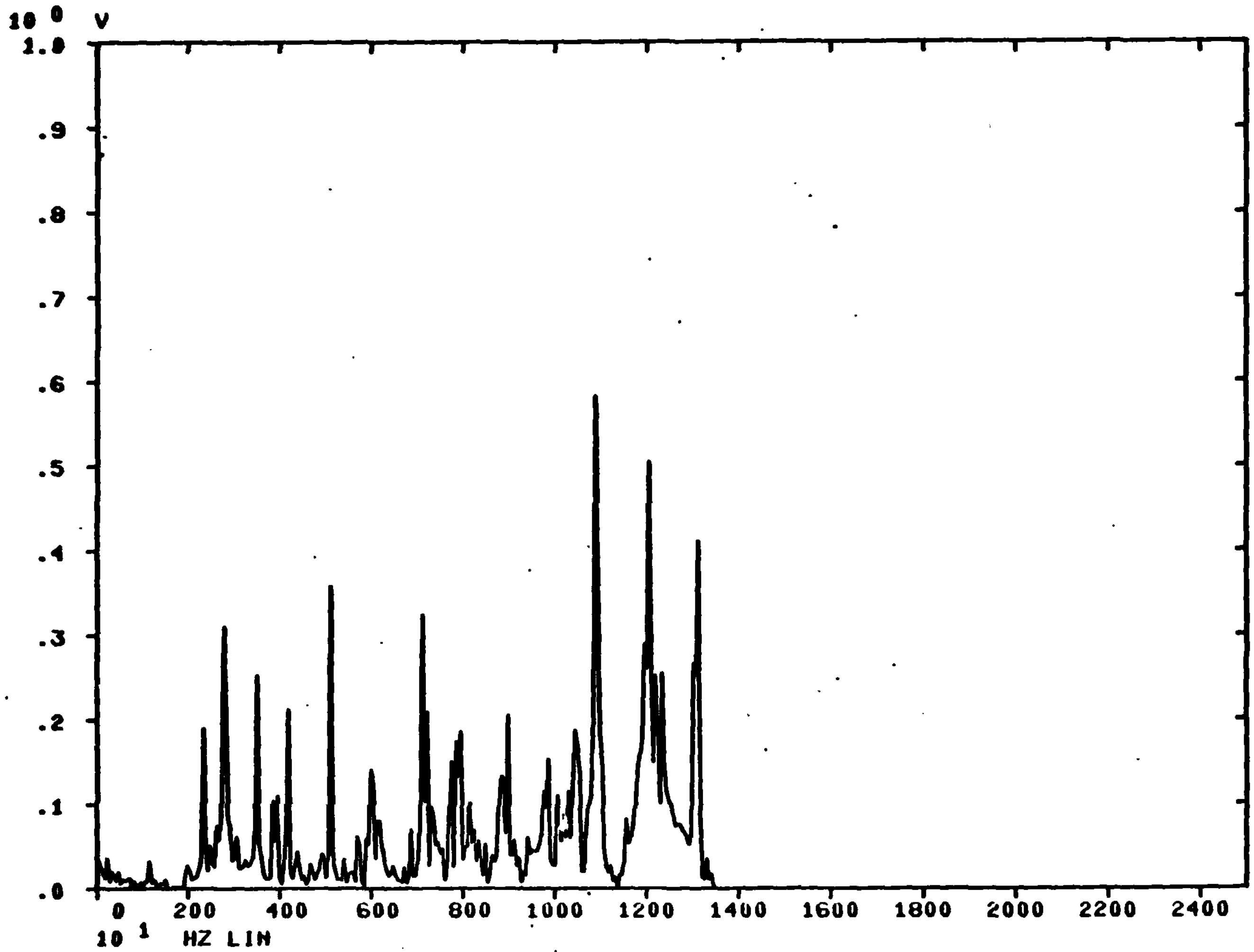


Figure 29. Polar presentation of transfer function for baseband measurement (0-50 lb. impulse hammer). Impact location C

TABLE III

SPECIMEN FREQUENCY SECTIONS (SPECIMEN FIXED)

SECTION NO.	START FREQ. (Hz)	STOP FREQ. (Hz)	CNTR. FREQ. (Hz)	DELTA FREQ. (Hz)
1	410	937	673	1.395
2	840	2,598	1,758	4.882
3	2,598	3,340	2,969	1.953
4	4,043	4,512	4,277	1.221
5	4,747	5,508	5,127	1.953
6	5,713	7,276	6,494	4.069
7	7,276	9,620	8,448	6.104
8	9,620	11,380	10,500	4.883

Modal analysis of the specimen sections was completed and the results are shown in the following table

TABLE IV

SPECIMEN MODES AND DAMPING FACTORS (SPECIMEN FIXED)

SECTION NO.	NO. OF MODES	AVERAGE DAMPING FACTORS (%)	STANDARD DEVIATION OF DAMPING FACTOR
1	1	0.1755	----
2	2	0.2173	0.1088
3	3	0.0559	0.0063
4	2	0.0883	0.0025
5	2	0.0958	0.0576
6	6	0.1310	0.0542
7	5	0.0917	0.0541
8	5	0.1000	0.0396

The overall average damping factor for the specimen is about 0.1112% with an overall standard deviation of about 0.0601%.

B. SPECIMEN REMOVED FROM FIXTURE AND TEST CHAMBER

In order to ascertain the effects of the specimen fixture and test chamber, one additional test was conducted on the same specimen. During this test the specimen was removed from the fixture and test chamber. The specimen was laid flat on 3/4 inch foam rubber. No other support was provided.

Response and impulse hammer locations are identical to the previous test. Frequency ranges for use of the large (0-500 lb.) impulse hammer and small (0-50 lb.) impulse hammer remained unchanged.

The baseband plots for large and small impulse hammer for locations A, B, and C are presented in Figures 30 through 35. For the large impulse hammer four ranges of zoom were completed, and for the small impulse hammer five additional sections were zoomed. Specimen frequency sections are tested in Table V.

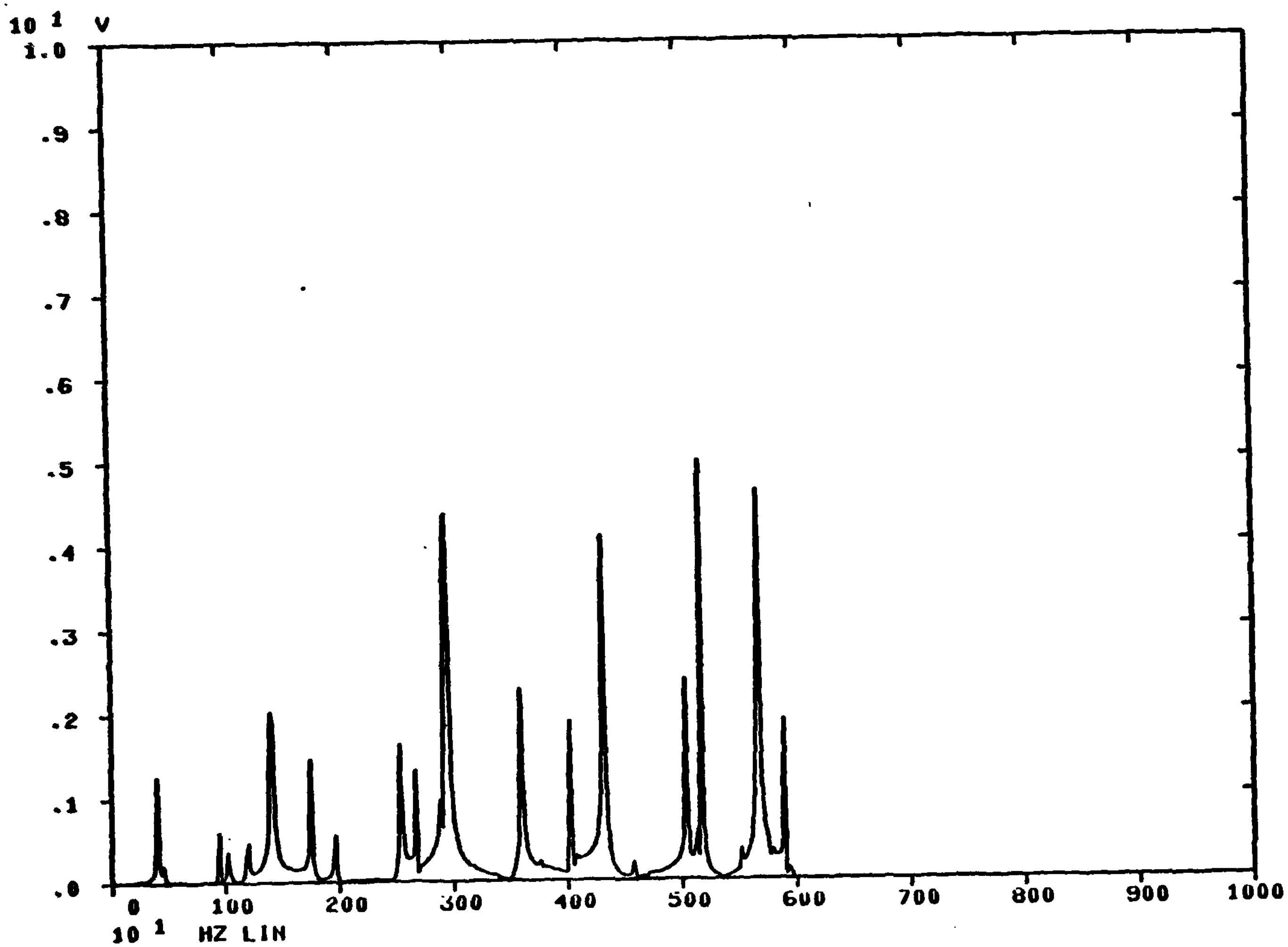


Figure 30. Polar presentation of transfer function for baseband measurement (0-500 lb. impulse hammer). Impact location A

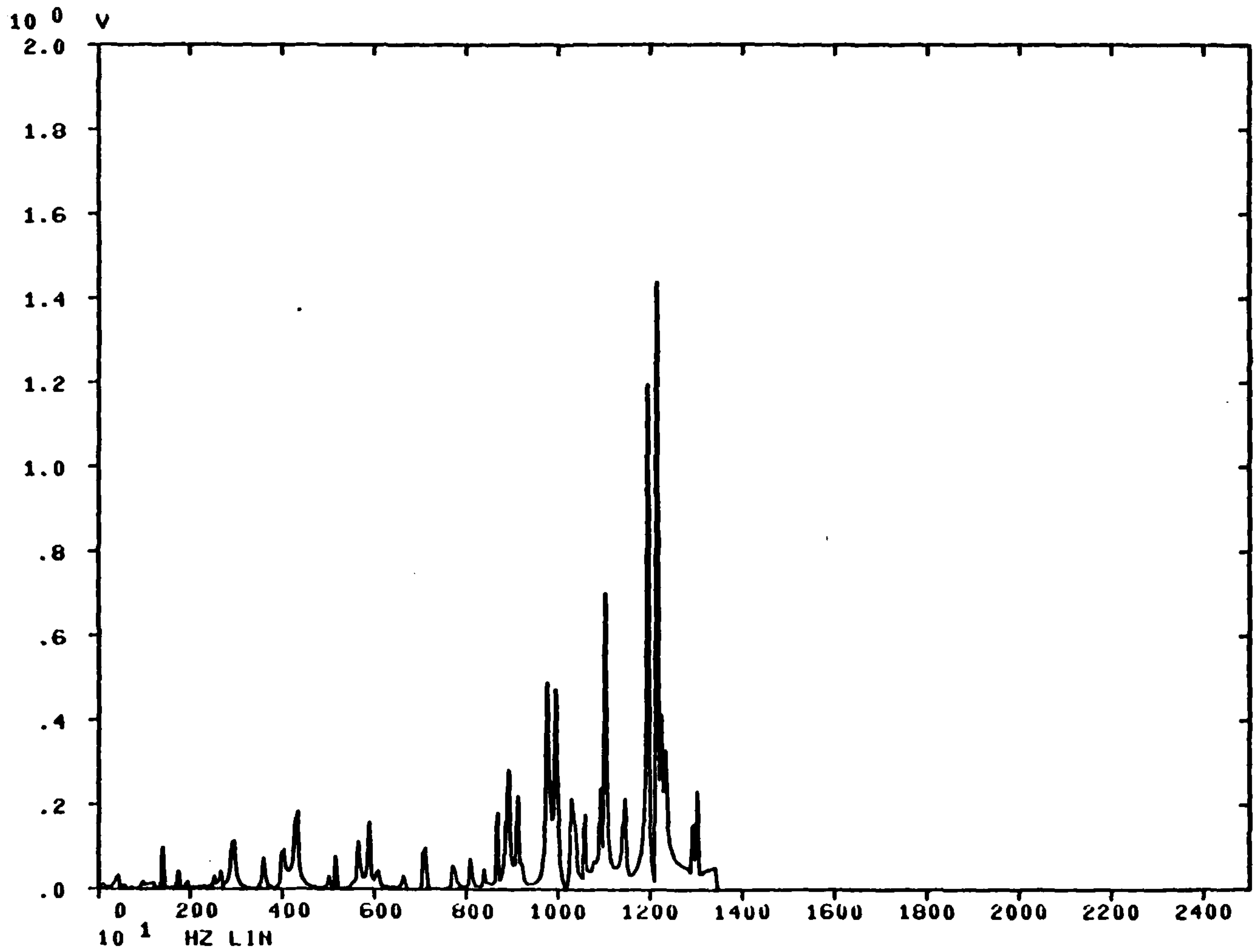


Figure 31. Polar presentation of transfer function for baseband measurement (0-50 lb. impulse hammer). Impact location A

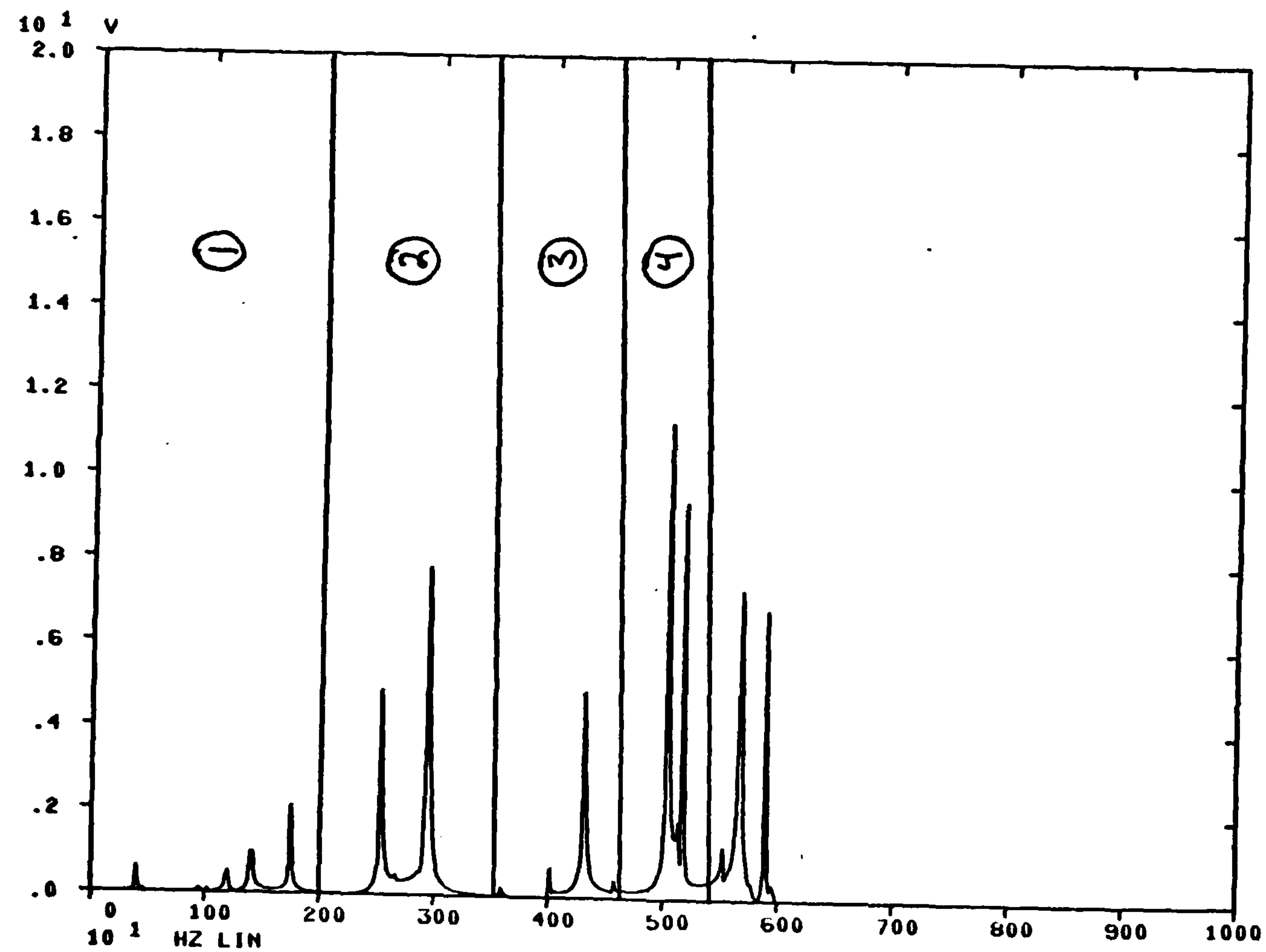


Figure 32. Polar presentation of transfer function for baseband measurement (0-500 lb. impulse hammer). Impact location B. Zoom ranges identified

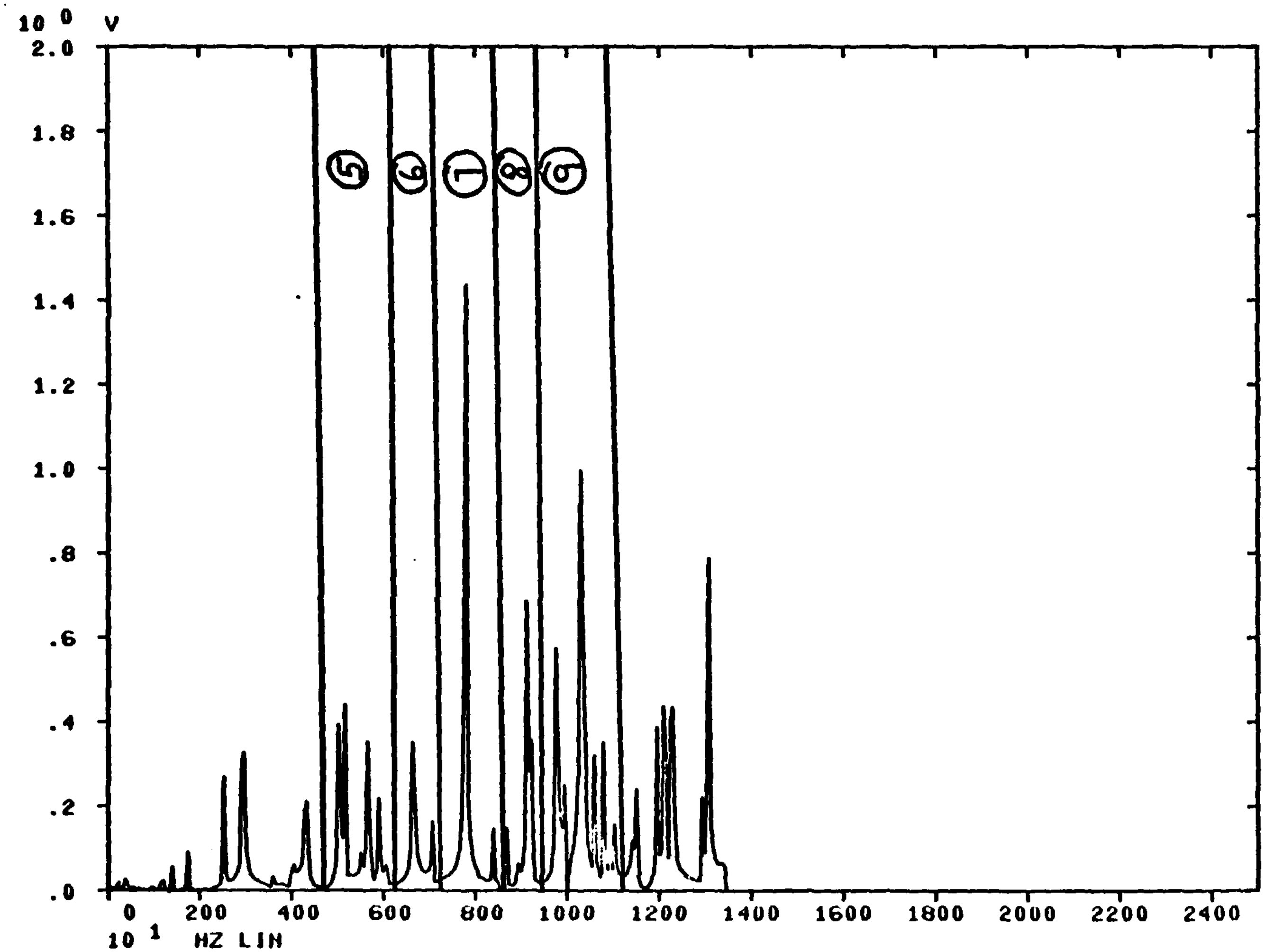


Figure 33. Polar presentation of transfer function for baseband measurement (0-50 lb. impulse hammer). Impact location B. Zoom ranges identified

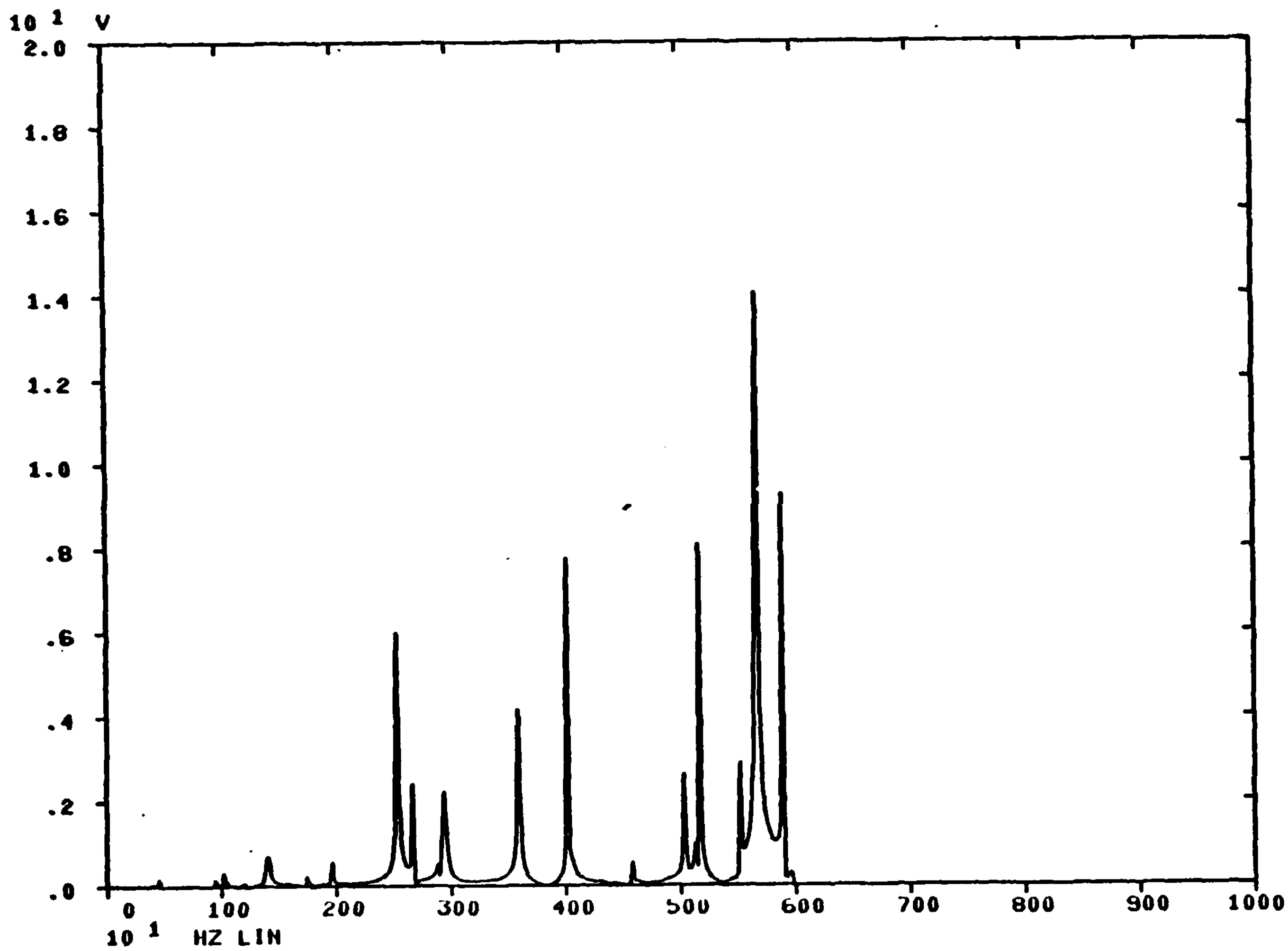


Figure 34. Polar presentation of transfer function for baseband measurement (0~500 lb. impulse hammer). Impact location C

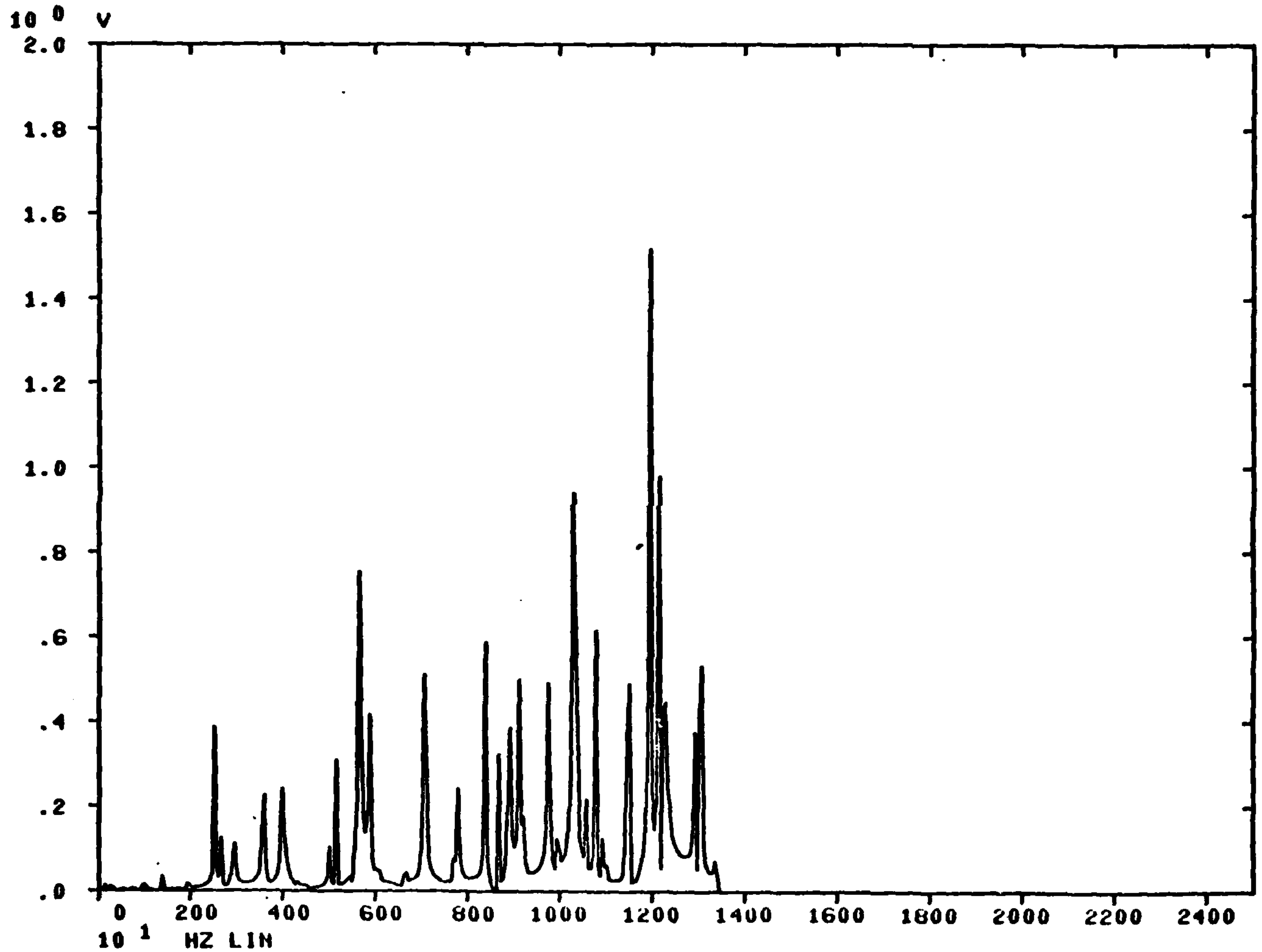


Figure 35. Polar presentation of transfer function for baseband measurement (0-50 lb. impulse hammer). Impact location C

TABLE V

SPECIMEN FREQUENCY SECTIONS (SPECIMEN FREE)

SECTION NO.	START FREQ. (Hz)	STOP FREQ. (Hz)	CNTR FREQ. (Hz)	DELTA FREQ. (Hz)
1	1094	1954	1524	2.441
2	1915	3555	2735	4.883
3	3575	4610	4092	3.255
4	4610	5293	4951	1.953
5	4688	6299	5493	4.069
6	6250	7227	6738	2.441
7	7276	8594	7935	3.441
8	8545	9473	9009	2.441
9	9424	11,190	10,307	4.883

Modal analysis was compled on the free specimen, and the results are tabulated below in Table VI.

TABLE VI

SPECIMEN MODES AND DAMPING FACTORS (SPECIMEN FREE)

SECTION NO.	NO. OF MODES	AVERAGE DAMPING FACTORS (%)	STANDARD DEVIATION OF DAMPING FACTOR
1	2	0.0885	0.0064
2	5	0.1264	0.0774
3	1	0.0339	N/A
4	3	0.0265	0.0017
5	2	0.0295	0.0020
6	4	0.0250	0.0080
7	5	0.0331	0.0195
8	3	0.0209	0.0123
9	3	0.0301	0.0069

Again, all raw data sheets are included in Appendix F. The overall average damping factor for the free specimen is about 0.0500% with an overall standard deviation of about 0.0504%.

VII. RESULTS AND CONCLUSIONS

Mode identification was accomplished utilizing the zoom feature of the HP-5451C Fourier Analyzer. After a baseband test was conducted and results stored (Figure 22), any section could be chosen to zoom. For example, zooming section 1 of the test chamber results in a plot as shown in Figure 36. The initial display will be in polar form and must be converted to rectangular (one button function on the HP-5451C) as shown in Figure 37. As shown in Figure 38, the coherence for this test was very good, and the data may be assumed to be accurate. For mode identification it is necessary to get a Nyquist plot of the data (in rectangular form). The Nyquist plot is vector representation of the real vs. imaginary values of the data. On a Nyquist a pure mode would sweep out a perfect circle. Modes with differing damping factors exhibit circles with varying radius. Figure 39 shows the Nyquist plot of the zoom data. Note there are many modes present with greatly varying damping factors. Individual modes can be isolated by inspection of a small portion of the rectangular data. For example, Figure 40 shows the rectangular plot from about 675 Hz to about 850 Hz. If the isolated portion is converted to Nyquist, as shown in Figure 41, the major mode at 772 Hz is readily identified. The Nyquist plots can be smoothed (made more circular) by higher resolution. That is, complete a zoom measurement on a smaller frequency band.

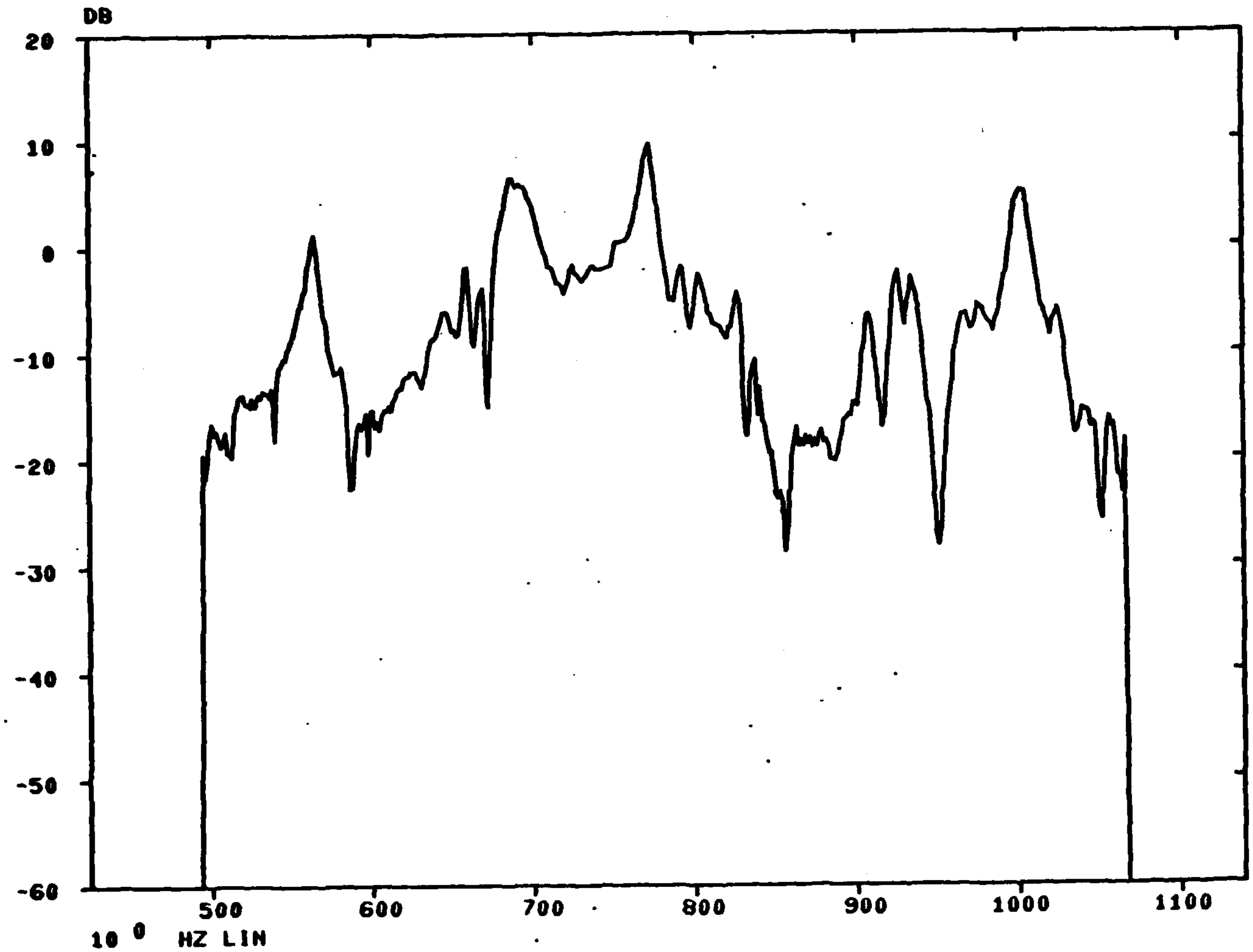


Figure 36. Zoom of test chamber section 1

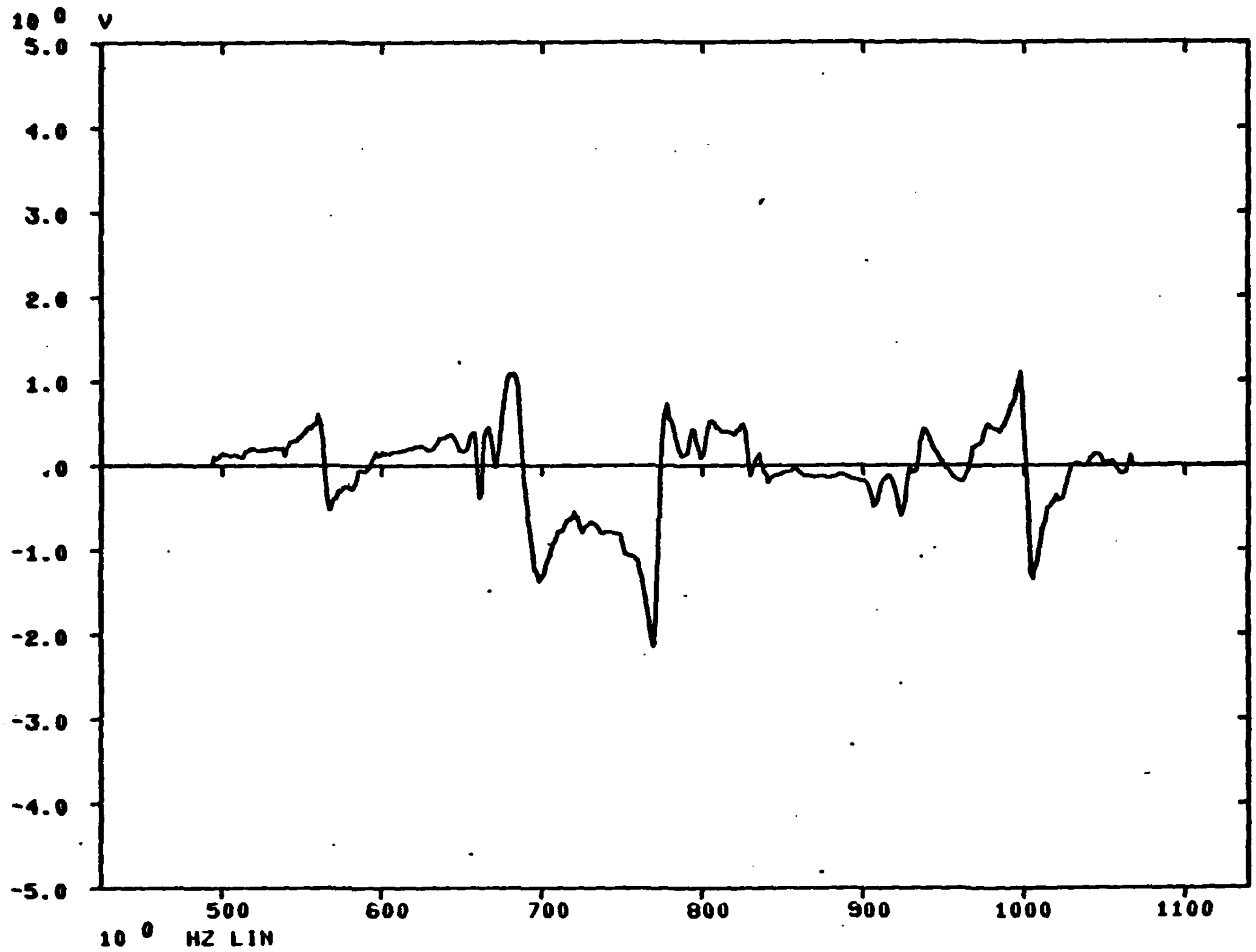


Figure 37. Zoom of test chamber, section 1. Rectangular form

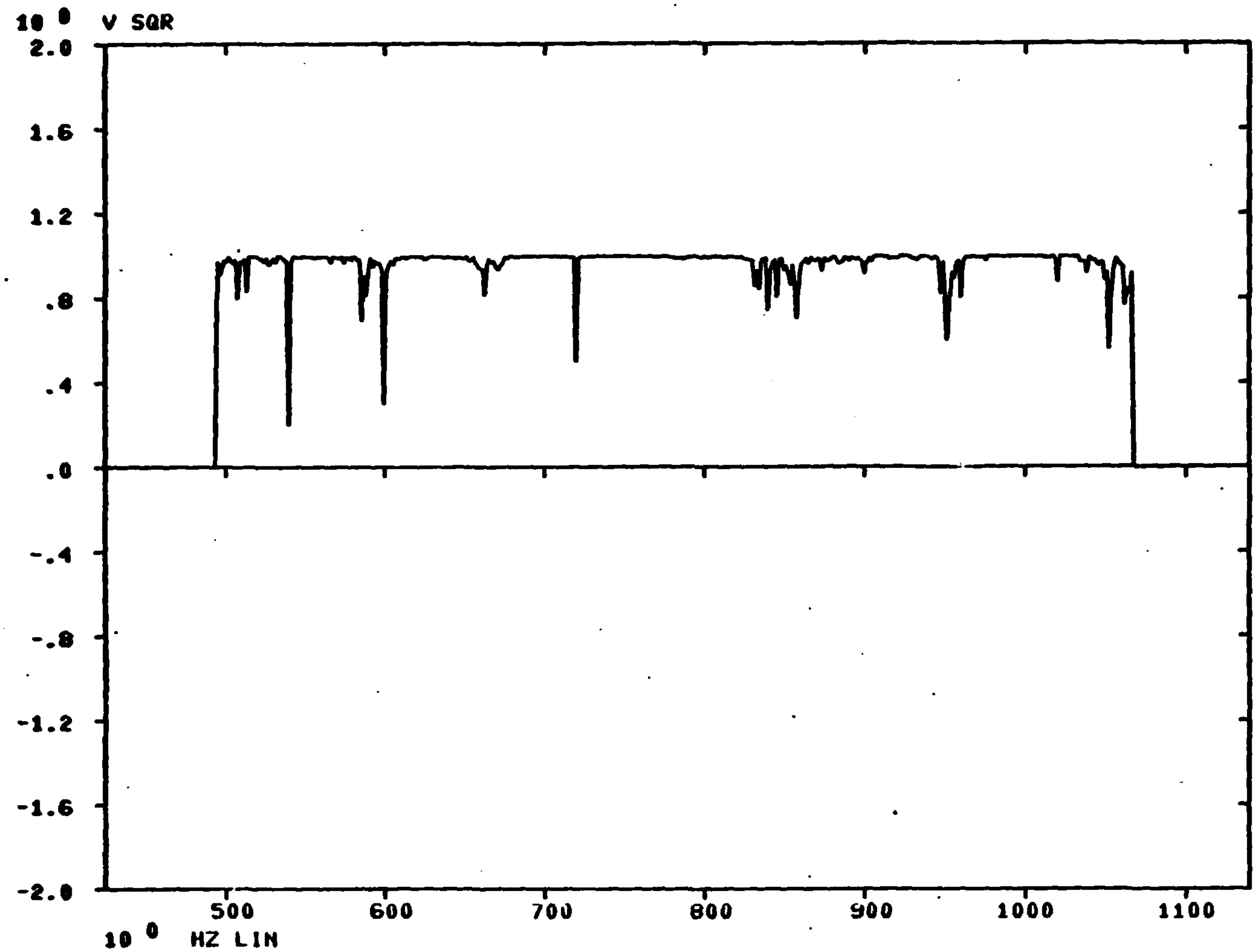


Figure 38. Zoom of test chamber, section 1. Coherence

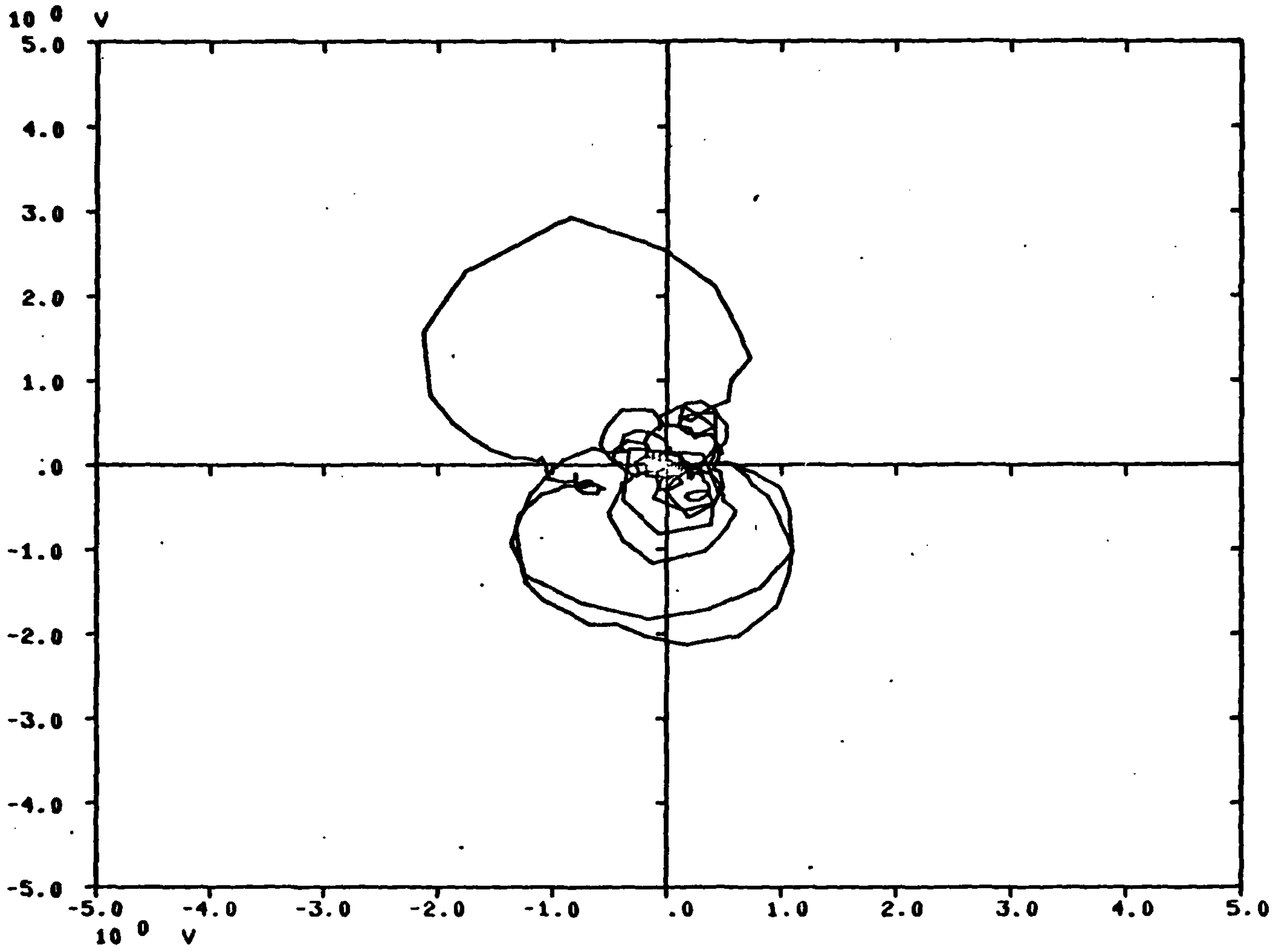


Figure 39. Zoom of test chamber, section 1. Nyquist plot

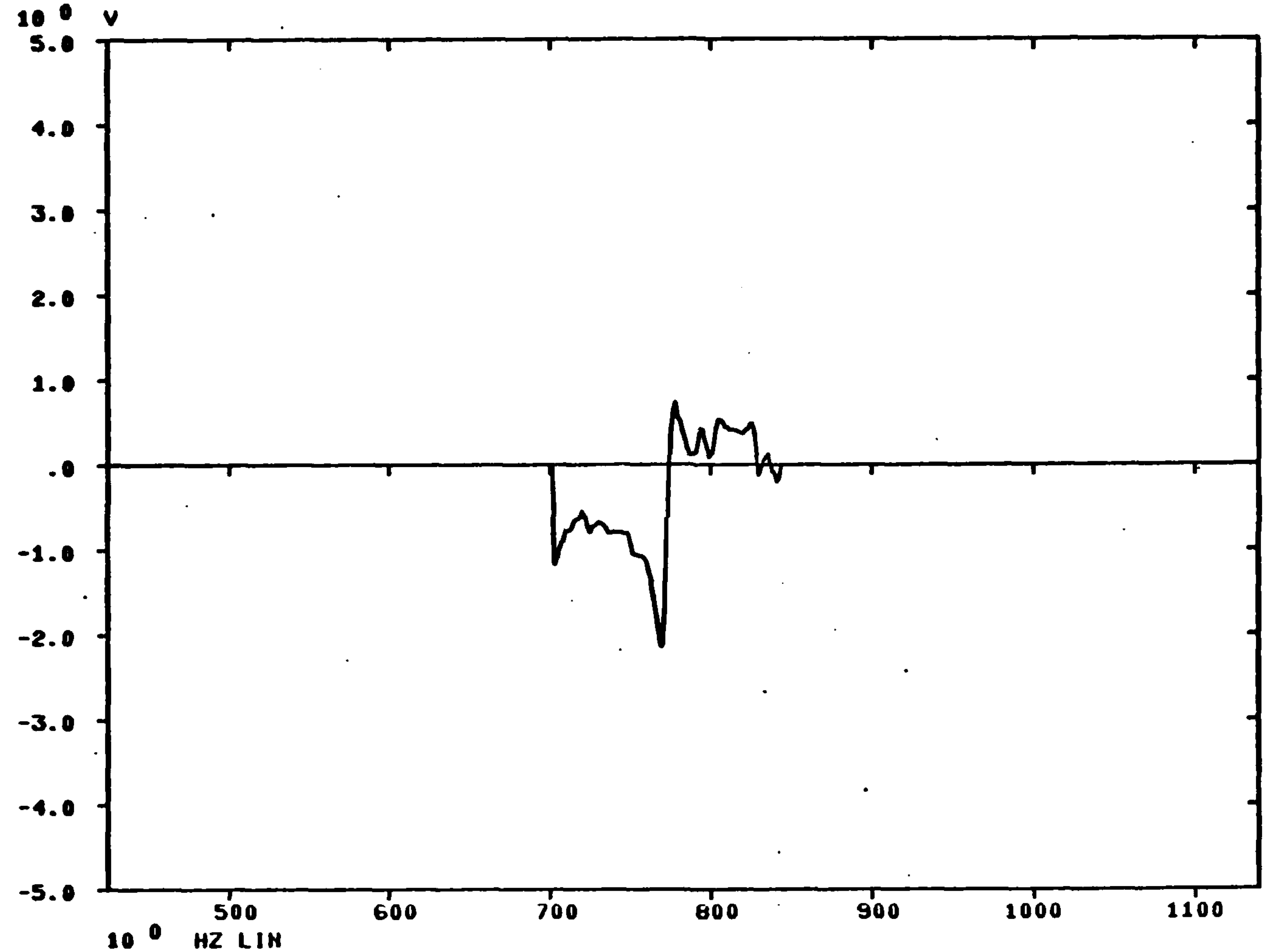


Figure 40. Zoom of test chamber, section 1. Isolated portion of rectangular data

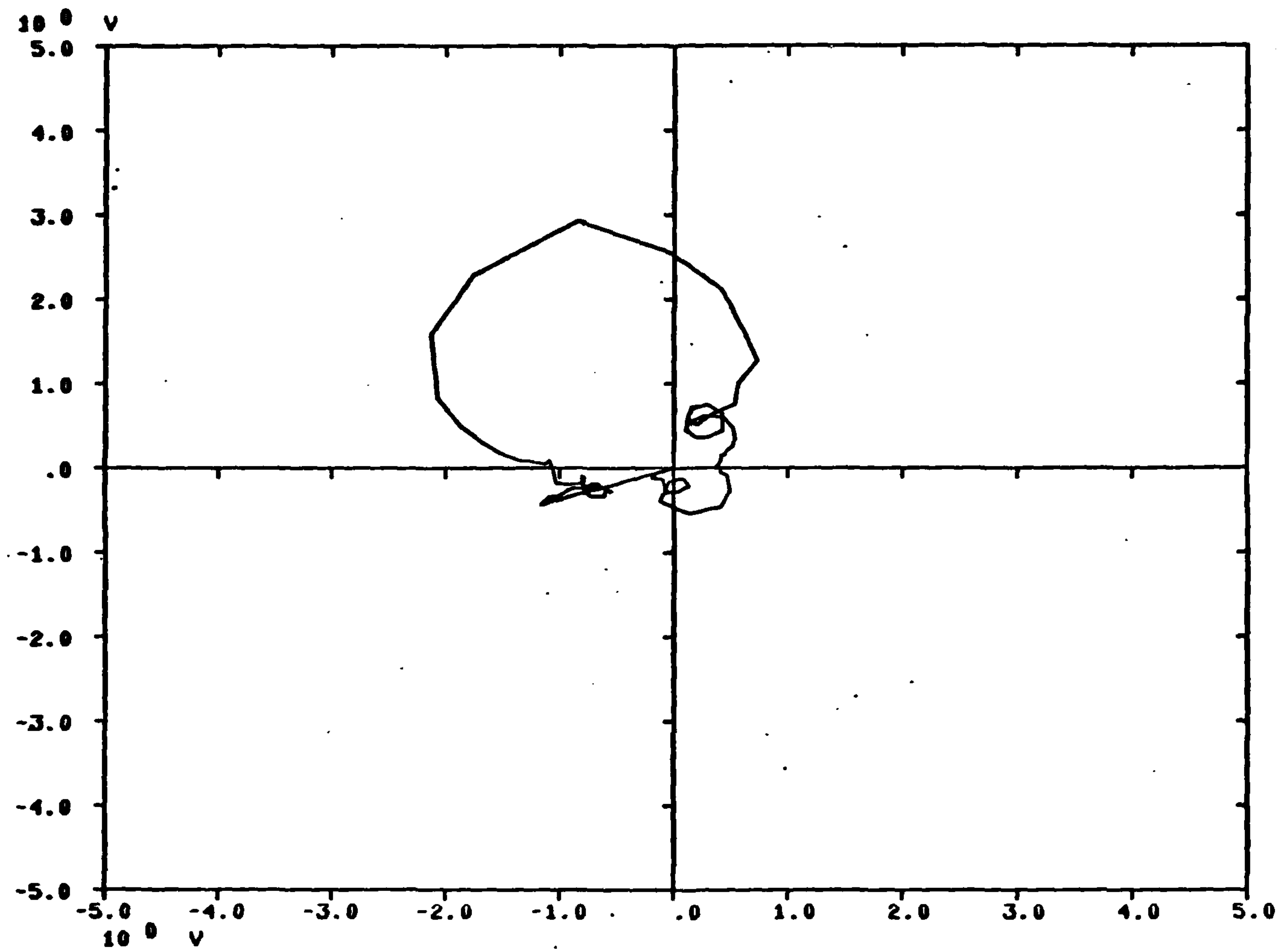


Figure 41. Zoom of test chamber, section 1. Isolated portion of Nyquist plot

All modes identified for the test chamber and the specimen (both fixed and free) are listed in the tables included in Appendices E and F.

It was noted that there are many more modes for the test chamber than for the specimen, but that is expected because the test chamber is a much more complex system, and the boundary conditions are considerably more complex.

The number of modes for the specimen in the test chamber is found to be 26, whereas the number of modes of the specimen separated from the test chamber is 28. This is good agreement, and it should be noted that the modes of the test chamber did not increase the number of observed modes of the specimen.

The average damping factor observed for the test chamber is about 0.47%, which is a typical value for plain carbon steel. The average damping factor for the specimen (fixed) is about 0.11%, and for the specimen (free) is about 0.05%. As expected, the fixing of one end of the specimen in the test chamber did increase the measured damping factor, but with more testing it is possible to quantify the increase and make suitable corrections.

A plot of damping factors vs. frequency for the test chamber is presented in Figure 42. The damping factor is higher at lower frequencies with the maximum damping factors being in the range of 1500-3000 Hz. After 3000 Hz the damping factor averages out to about 0.2% at higher frequencies.

TEST CHAMBER

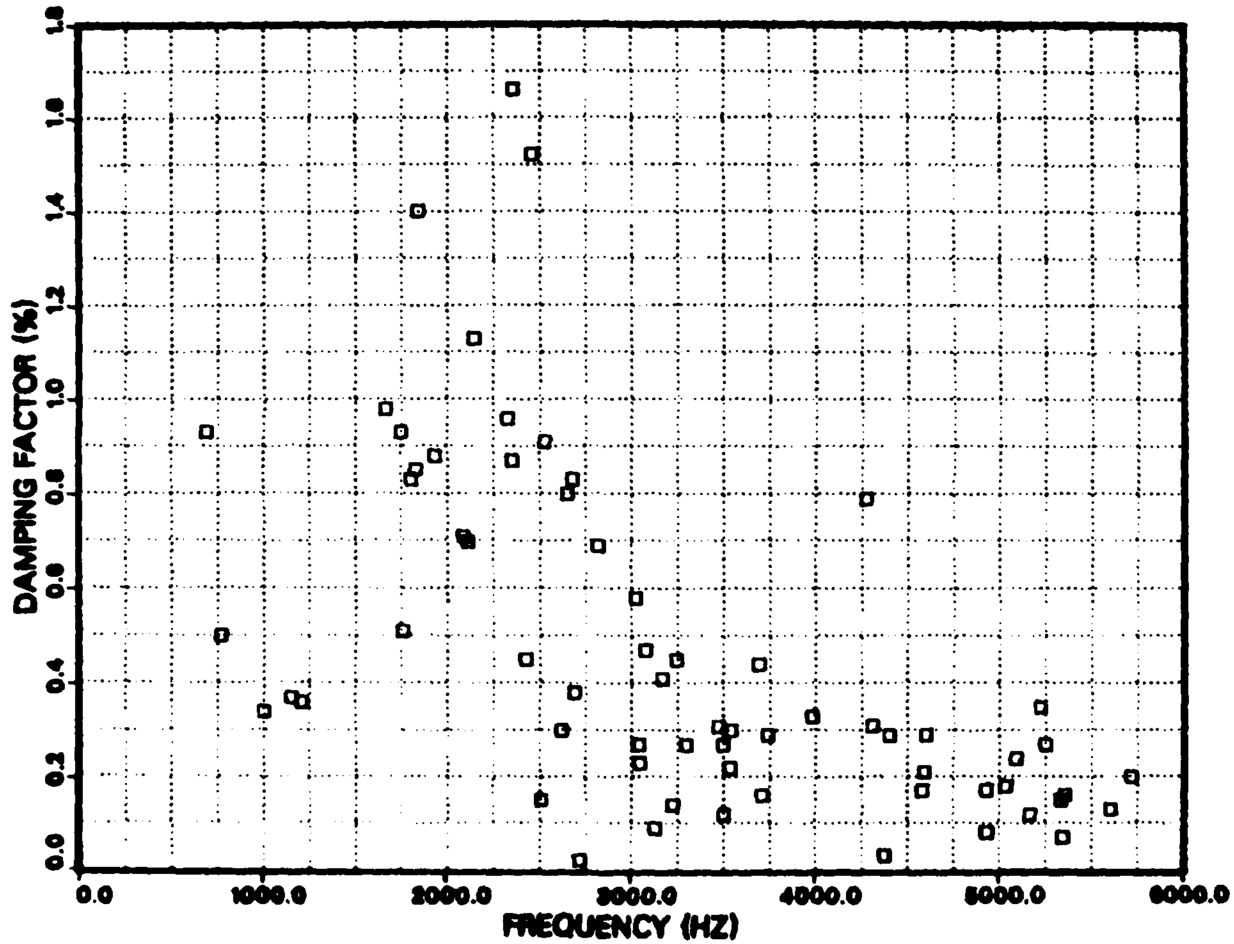


Figure 42. Test chamber--damping factor vs. frequency

For the specimen, damping factors vs. frequency (for both fixed and free) are presented in Figures 43 and 44. Like the test chamber, the damping factor appears to be higher at lower frequency for the fixed specimen, and without question this same trend is observed for the free specimen. The fixed specimen damping factor levels out to about 0.10% at higher frequencies, and for the free specimen it levels out to about 0.025%.

SPECIMEN (FIXED)

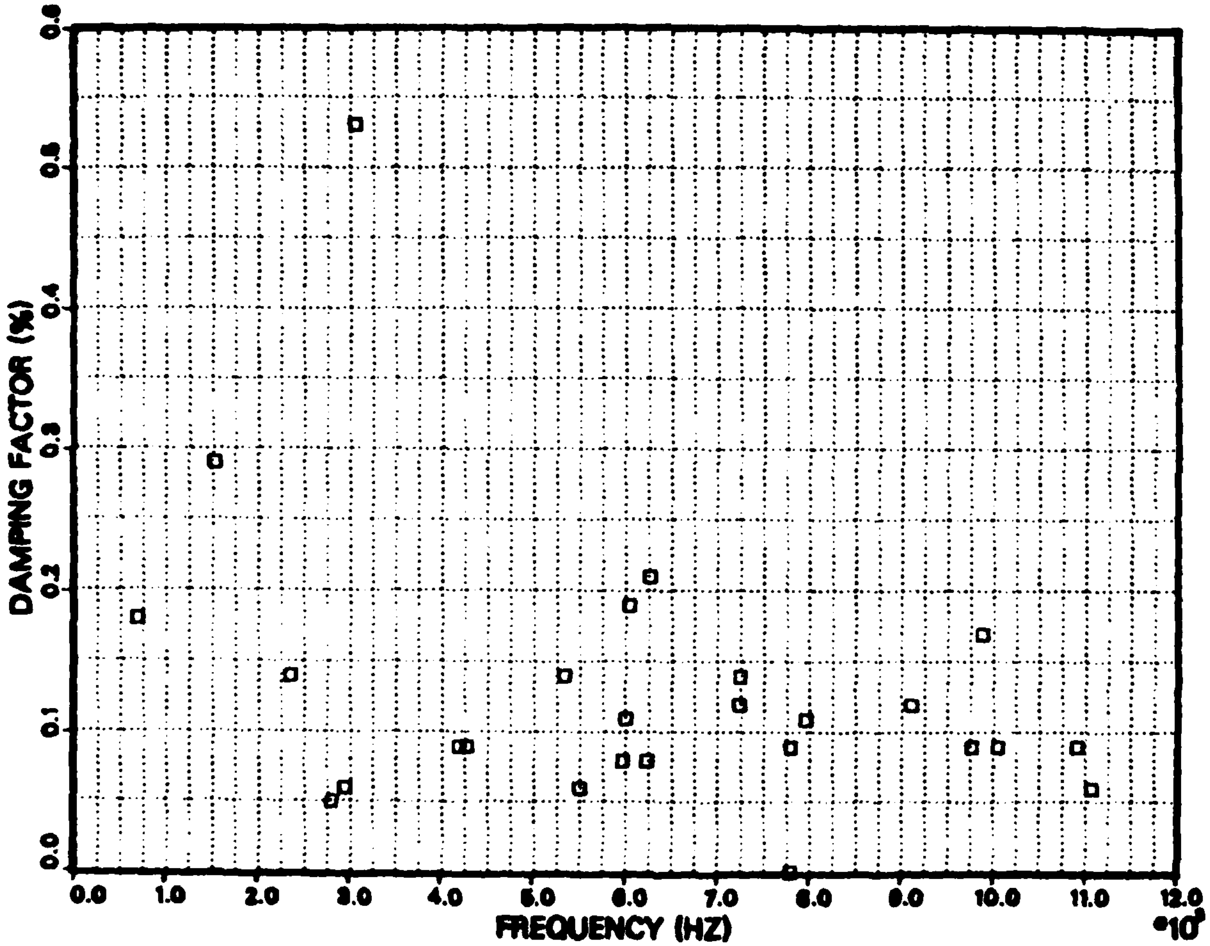


Figure 43. Specimen damping factor vs. frequency (specimen fixed)

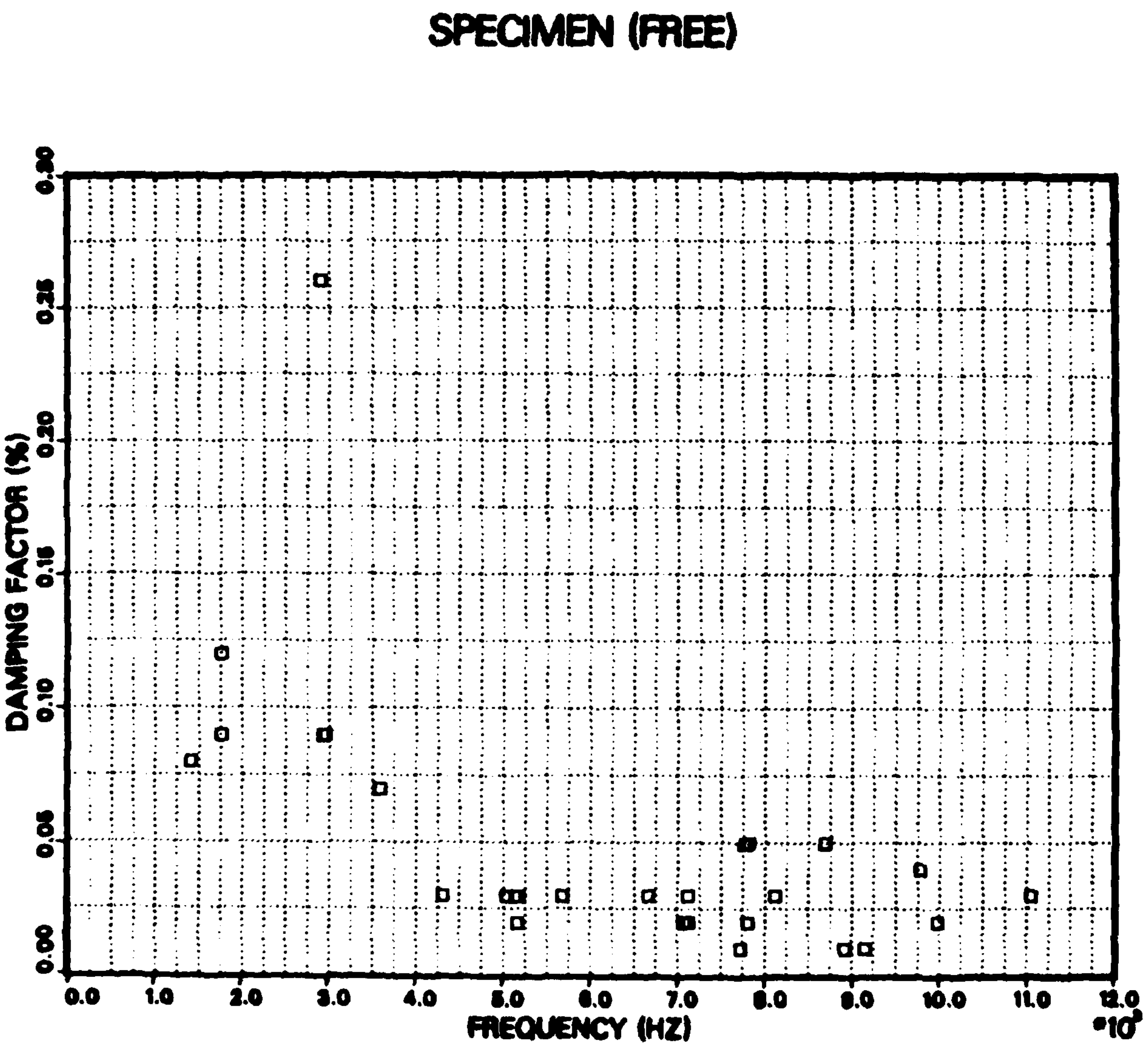


Figure 44. Specimen damping factor vs. frequency (specimen free)

VIII. RECOMMENDATIONS FOR FUTURE WORK

1. Expand the test procedure to include random excitation of test specimen for the energy input and measurement of responses up to 15,000 Hz.

2. Conduct similar tests on various materials including high damping materials such as Incramute and Sonoston.

3. Investigate the temperature dependence of viscous damping, especially for constrained layer and non-metallic composites.

4. Investigate the changes in damping for materials immersed in a water medium at varying temperatures.

APPENDIX A

THE HP-5451C FOURIER ANALYZER

The HP-5451C Fourier Analyzer System performs analysis of time and frequency data containing frequencies from DC to 50 KHz. The system analyzes time-series data such as mechanical vibrations, sonar echoes, tidal action, biomedical phenomena such as brain waves and nerve impulses, voltages and currents in electronic systems, and acoustic phenomena. These analyses may detect signals hidden in noise, or may locate critical functions in complex systems. Both continuous and transient data may be processed.

Keyboard programming allows the following operations automatically without special software:

A. Forward and inverse Fourier transform

B. Magnitude and phase spectrum

C. Power and cross power spectrum

D. Transfer function

E. Coherence function

F. Convolution

G. Auto and cross correlation

H. Hanning and other weighting functions

I. Histogram

J. Scaling

K. Ensemble averaging (time and frequency)

Six editing keys operate an on-line resident editor so that a sequence of steps configured into an automatic measurement procedure may be changed on-line without the need to do off-line editing, compiling and testing. In fact, the series of steps or programs used to perform a particular operation can be stored on the Disc for easy re-entry into the Fourier Analyzer.

Data input and output is likewise controlled from the keyboard. Data can be entered in analog form through the four channel Analog-to-Digital Converter, or in digital form.

Results of all operations are displayed on the oscilloscope. In addition, results can be printed out in decimal numbers or plotted on the Graphics Terminal or an X-Y plotter.

The Fourier Analyzer is a completely calibrated system; all displays and data output are accompanied by a scale factor relating them to physical units. This calibration results from digital techniques being used in all computations.

HP-5451C SPECIFICATIONS AND CHARACTERISTICS

SPECIFICATIONS

(Specifications describe the standard system's warranted performance.)

ANALOG-TO-DIGITAL CONVERTER

Input Voltage Range: ±0.125V to ±8V peak in steps of 2.

Input Coupling: dc or ac.

Input Channels: 2 channels wired for 4 standard. 4 channels optional with plug-in cards.

Resolution: 12 bits including sign.

Input Frequency Range: dc to 50 kHz, 5 Hz to 50 kHz, ac coupled (100 kHz optional).

Sample Rate:

- **Internal:** 100 kHz max. (1, 2, 3, or 4 channels simultaneously). (200 kHz optional on 1, 2, 3, or 4 channels.) [50 kHz max. (3 or 4 channels simultaneously).†]
- **External:** An external time base may be used to allow external control of the sampling rate up to 100 kHz (200 kHz optional). One sample can be taken for each clock pulse (TTL level).

Internal Clock Accuracy: ±0.01%.

DISPLAY UNIT

Vertical Scale Calibration: Data in memory is automatically scaled to give a maximum on-screen calibrated display. The scale factor is given in volts/division, volts²/division, or in dB offset.

Log Display Range: 80 dB with a scale factor ranging from 0 to +998 dB. Offset selectable in 4 dB steps.

Linear Display Range: ±4 divisions with scale factor ranging from 1×10^{-512} to 5×10^{512} in steps of 1, 2, and 5.

Digital UP/DOWN Scale: Allows 8 up-scale and 2 down-scale steps (calibrated continuous scale factor).

Horizontal Scale Calibration:

- **Linear Sweep Length:** 10, 10.24 or 12.8 divisions.
- **Log Horizontal:** 0.5 decades/division.
- **Markers:** Intensity markers every 8th or every 32nd point.

BASE SOFTWARE

Transform Accuracy: The expected rms value of computational error introduced in either the forward or inverse FFT will not exceed 0.1% of the rms value of the transform result.

Dynamic Range: >75 dB for a minimum detectable spectral component in the presence of one full scale spectral component after twenty ensemble averages for a block size of 1024.

EXECUTION TIMES*

Fourier Transform: <55 ms

Stable Power Spectrum Average: <80 ms

Stable Tri-Spectrum Average: <220 ms

REAL TIME BANDWIDTHS*

Fourier Transform: >7.5 kHz

Stable Power Spectrum Average: 5.4 kHz

Stable Tri-Spectrum Average: 1.9 kHz

MASS STORAGE SOFTWARE

MAXIMUM REAL TIME DATA ACQUISITION RATE (Single Channel):

BS 256: 10 kHz

BS 1024: 39 kHz (25 kHz†)

BS 4096: 80 kHz (30 kHz†)

OFF-LINE BSFA SOFTWARE

Center Frequency Range: dc to one-half the Real Time Data Acquisition Rate.

Center Frequency Resolution: Continuous resolution to the limit of the frequency accuracy for center frequencies >0.02% of the sampling frequency.

Frequency Accuracy: ±0.01%

Bandwidth Selection: In steps of $f/5n$ where $n = 2, 3, 4$, etc.

Max. Resolution Enhancement: >400

Dynamic Range:** 90 dB from peak out-of-band spectral component to the peak level of the passband noise. 80 dB from peak in-band spectral component to the peak level of the passband noise.

Out-of-Band Rejection: >90 dB

Passband Flatness of the Digital Filter: ±0.01 dB

ENVIRONMENTAL CONDITIONS

Temperature Range: 0°C to 40°C (104°F).

*For band limited random noise type signals at block size 1024, no display, no Hanning.

**After eight ensemble averages of a power spectrum at block size 1024. Reduced by 10 dB at the exact center of the band.

†These rates apply to systems with modules 5446B and 54451A/B having a serial prefix lower than 1842.

SUPPLEMENTAL CHARACTERISTICS

(Supplemental Characteristics are intended to provide useful information for system applications by giving typical, but not warranted, performance parameters.)

ANALOG-TO-DIGITAL CONVERTER

Input Impedance: 1 MΩ in parallel with <75 pf.

Sample Rate Control:

Maximum Frequency Mode: Maximum frequency selectable from 0.1 Hz to 50 kHz (100 kHz optional) in steps of 1, 2.5, 5. This mode automatically sets maximum frequency independent of block size.

Frequency Resolution Mode: Frequency resolution selectable from 0.2 mHz to 1000 Hz in steps of 1, 2, 5. This mode automatically sets frequency resolution and sample record length independent of block size.

Input Mode: There is a buffered and non-buffered analog mode. In the buffered mode, other operations can be performed on previously collected data while the ADC collects current input data into a buffer.

DISPLAY UNIT

Data may be displayed in single sweeps or refreshed continuously in the following forms:

Y Axis	X Axis
Amplitude	Time (Linear or Log)
Real Part	Frequency (Linear or Log)
Imaginary Part	Frequency (Linear or Log)
Magnitude (Linear or Log)	Frequency (Linear or Log)
Phase	Frequency (Linear or Log)
Imaginary Part (NYQUIST PLOT)	Real Part

CRT Positioning: Three markers to aid in adjusting trace position as well as vertical and horizontal controls are provided for display positioning.

Origin: Left edge of display, zero amplitude.

+FS: *Positive full scale, center of display.*

-FS: Negative full scale, center of display.

Analog Plotter Output: Any displayed data can be output to a plotter or remote oscilloscope. HP 10640B interface is required for operation.

Amplitude: 0.5V per oscilloscope display division.

Linearity: 0.1% full scale.

Interpolation: *Linear interpolation in 0.05% steps.*

Type of Display: Points, bars, or continuous (interpolation).

BASE SOFTWARE

System Accuracy and Range: The Fourier Transform is implemented using conditional scaling for maximum accuracy with no data overflows allowed. All calculations use floating point arithmetic on a block basis with full 16- and 32-bit arithmetic where applicable.

Data Word Size: 16-bit imaginary with 32 bits preserved for double precision functions. Division, addition, or subtraction operations performed in 16 or 32 bits depending on data.

Maximum Block Size: 4096 time domain points.

Minimum Block Size: 64 time domain points.

Permanent Data Space: 28K words (16K words standard in systems with serial prefix below 1842, optionally expandable to 28K with option 011).

Permanent Program Space: 32K words.

BSFA SOFTWARE

Maximum BSFA Blocksize: 1024 time domain points. (2048 with option 670.) See also Table 5-1 in BSFA section of manual.

MASS STORAGE

Disc Unit:

Capacity: 2.45 megawords

Data Transfer: 2.5 million bits/second

Discs: 2 *(1 fixed, 1 removable)*

% of Real Time at 100 kHz ADC Sampling Rate (Single Channel):
BS 256: 10% **BS 1024:** 39% (25%†) **BS 4096:** 80% (30%†)

Number of Records Per File:

Data Block: 214 records (4096 blocksize maximum/record).

ADC Throughput: 199 records (4096 blocksize max./record).

Program Stack: 138 records (470 steps/record).

ASCII Text: 690 records (128 words/record).

Index: 69 records (10 pointers/record).

System Coreload: *4 records (32K words/record).*

Common: 286 records (256 words/record).

Overlay: 20 overlays (8K words maximum, 7K words maximum with option 261 or 265).

OPTIONS 261 & 265

The magnetic tape options are used for ADC Throughput only.

Maximum Real Time Data Acquisition Rate (Single Channel):

Opt. 261		Opt. 265	
BS 256:	6 kHz	**BS 256:**	9 kHz
BS 1024:	12 kHz	**BS 1024:**	21 kHz
BS 4096:	15 kHz	**BS 4096:**	30 kHz

Number of Tracks: 9

Read/Write Speed: 45 ips

Density: *Option 261, 800 bpi; Option 265, 1600 bpi.*

Data Transfer Rate: Option 261, 36K cps max.; Option 265, 72K cps max.

Rack Height: 610 mm (24 in.)

POWER REQUIREMENTS, SIZE, WEIGHT

Power Source: 115/230 volts ±10%, 50/60 Hz. 1800 watts typical for base system.

Size: Dimensions are for a typical system (excluding cabinet and terminal).

Height: 771 mm (28 in.); **Width:** 425 mm (16¾ in.);

Depth: 616 mm (24¼ in.).

Cabinet:

Panel Height: 1422 mm (56 in.)

Overall: 1631 mm (64¼ in.), height; 533 mm (21 in.), width; 762 mm (30 in.), depth.

Weight: Net weight for a base system (excluding terminal) — 163.3 kg (358 lbs.).

Price and Ordering Information: Consult the 5451C Fourier Analyzer System's *Ordering Information Guide.*

SYSTEM INSTALLATION

Included in the 5451C System is on-site installation. On installation, a trained Hewlett-Packard representative will perform an operational demonstration to ensure that the system is functioning normally.

TRAINING

A course on Fourier analysis and system operation is optionally available at HP's Santa Clara, California facility. On-site training can also be provided, if desired.

†These percentages apply to systems with modules 5466B and 5451A/B having a serial prefix lower than 1842.

APPENDIX B

HP-5451C TRANSFER FUNCTION AND POWER SPECTRUM
FLOW CHART AND PROGRAM LISTING

This appendix contains flow charts and listings of the pre-written soft key programs shipped on the 5451C operating disc pack. These programs are for the Gold Key F2 (Transfer Function) and F5 (Power Spectrum) soft keys. The purposes for including these flow charts and listings are as follows:

1. For those who wish to modify the programs to better fit specific applications.
2. As an example for those who wish to write their own soft key programs.
3. As a model for re-entering portions that may have been accidentally written over on the disc (programs reside in unprotected areas).

As an aid toward rapid understanding of these programs, a certain programming "style" has been used. As a result of this style, the programs are longer than they would otherwise need to be, but are easier to comprehend. Some elements of the style are described below.

BLOCK STRUCTURE THROUGH USE OF LABELS

The code in the programs is organized in "blocks" — functional segments which are delimited by LABEL instructions. A convention is followed in the choice of label numbers. The beginning of each block is designated by a label number ending in a multiple of 50, e.g. L1050. The block ends with the label 9 higher, e.g. L1059. Within the block, label numbers are between these limits, e.g. L1051, L1052 etc. One block may contain others — each will use the above delimiting convention.

Although the use of these labels lengthen the programs, it makes them much easier to understand, and to correlate with the flow diagrams. For example, when several branches of a program go to the same point, each branch will jump to its own appropriate label. Since these labels all appear together at one point in the program, one can tell that multiple branches converge at that point. An example is in the Transfer Function program, stack 54, where labels 1209, 1259 and 1609 all appear together. This is just one example of the way in which complex internal linkages in the program are made more visible.

BRANCHING THROUGH USE OF "COMPUTED GOTO's"

In most complex programs, branching is common. One means of branching is to use an IF statement, provided in Keyboard language by the "GOLD KEY" "SKIP" instruction. When there are more than two possible branches, however, use of IF branching tends to get complicated, involving multiple decision points. The "Computed GoTo" or "switch" type of branching statement is more suitable in such cases for simplicity of understanding. It has been used extensively in these keyboard programs, even for simple two way branching. By standardizing on it, the code becomes recognizable and easier to read.

In Keyboard language, the "Computed GoTo" is implemented by computing the number of a label and jumping to it. The following is an example.

```
L 1050                         Start of branch block
Y A+   0   1050   11D          Set variable 0 to 1050
  .                            + (the value of variable
                               11)
J 0D                           Jump to the label number
                               in variable 0
L 1051                         Code to be executed if
  .                            variable 11 = 1
  .
  .
J 1059                         Go to end of block
L 1052                         Code to be executed if
  .                            variable 11 = 2
  .
  .
  .
L 1059                         End of branch block
```

USE OF SUBROUTINES

In these programs there are several functions which have been set up as subroutines. These include the *parameter entry routine* (see below) and the measurement routines. The measurement routines are handled this way to simplify the flow of the main program and allow easy replacement of the measurement code in case you modify it in some way.

PARAMETER ENTRY ROUTINE

Since these programs ask the operator for many input parameters, a single subroutine, LABEL 100 in STACK 0, handles all the parameter entries. The routine is called with variable parameters 1 and 2 equal to the lower and upper limits on the range of allowable operator inputs. The routine reads your input, checks it against the range limits, and, if it is valid, passes it back to the calling program in (floating point) variable parameter 2000. If the input is out of range, this routine notifies you and waits for the new input. The routine will not return to the calling program until a valid input has been received.

PRECAUTIONARY NOTES

The following precautions apply to the operation of the preprogrammed measurements:

1. When using the standard software zoom (BSFA), the measurement blocksize can be no larger than 1024. When using the Option 670 Fourier Preprocessor for BSFA measurements, the maximum blocksize is 2048.

2. The maximum center frequency you may specify for a BSFA measurement is 32767 Hz.

3. The messages CF WHAT? or BW WHAT? may result if the center frequency and/or bandwidth you have chosen for your measurement are such that the BSFA analysis band is either less than 0 or greater than the ADC Fmax setting. Specifying different parameters should remove this problem.

4. The message DL WHAT? may occur when performing the on-line BSFA measurment. This is because the display is active during the on-line measurement. To remove this problem, either reduce the measurement bandwidth (thereby increasing the zoom power and lowering the data rate into the computer), or edit the appropriate keyboard stacks (stack 56 for transfer function, stack 61 for power spectrum) to remove parameter n3 from the calls to User Prog 45 for the on-line measurement (refer to commented program listings which follow).

5. When performing an off-line BSFA measurement with an optional Mag Tape unit, perform the following steps before making the measurement.

   Set:

   ADC SAMPLE MODE to INTERNAL KHz/μs
   MULTIPLIER to 100/10/5
   INPUT SELECTOR to A
   TRIGGERING to FREE RUN
   OVERLOAD VOLTAGE A to CHECK

   Enter:

   BLOCKSIZE 4096 ENTER
   MASS STORE 32 ENTER
   MASS STORE 22 SPACE 1 SPACE 150 ENTER
   MASS STORE 32 ENTER

   This writes 150 records of data on the magtape so that the magtape will be able to position to record 135 on the tape when the ADC throughput is performed. It will position by looking for the interrecord gaps written by the WRITE ADC throughput command.

6. After completing a BSFA measurement, be sure that all data space declared by the zoom programs is released by pressing RESTART.

As you go through the flow charts and commented listings, remember that these are only examples of programming the soft keys F1 through F6 on the Keyboard. It is up to you to determine which, if any, portions of these programs should be maintained. Because these programs are stored in unprotected areas of the Disc, there is the possibility they can be written over. If this should happen, you should enter the program stacks from the listing, substitute your own program, or copy from your back-up disc.

The soft key programs and the associated ASCII text and variable parameters were originally stored on the system disc pack in Files 3,4, and 7. The records used are as follows:

File 3 (Keyboard Programs)

Record 0
Records 51 through 62

File 4 (Text Buffers)

Text buffers 51 through 55
ASCII records 3245 through 3449*

File 7 (Common)

Common) Record 0

*This assumes that there are 3700 records in File 4. If not, the first and last ASCII text records may be computed as follows:

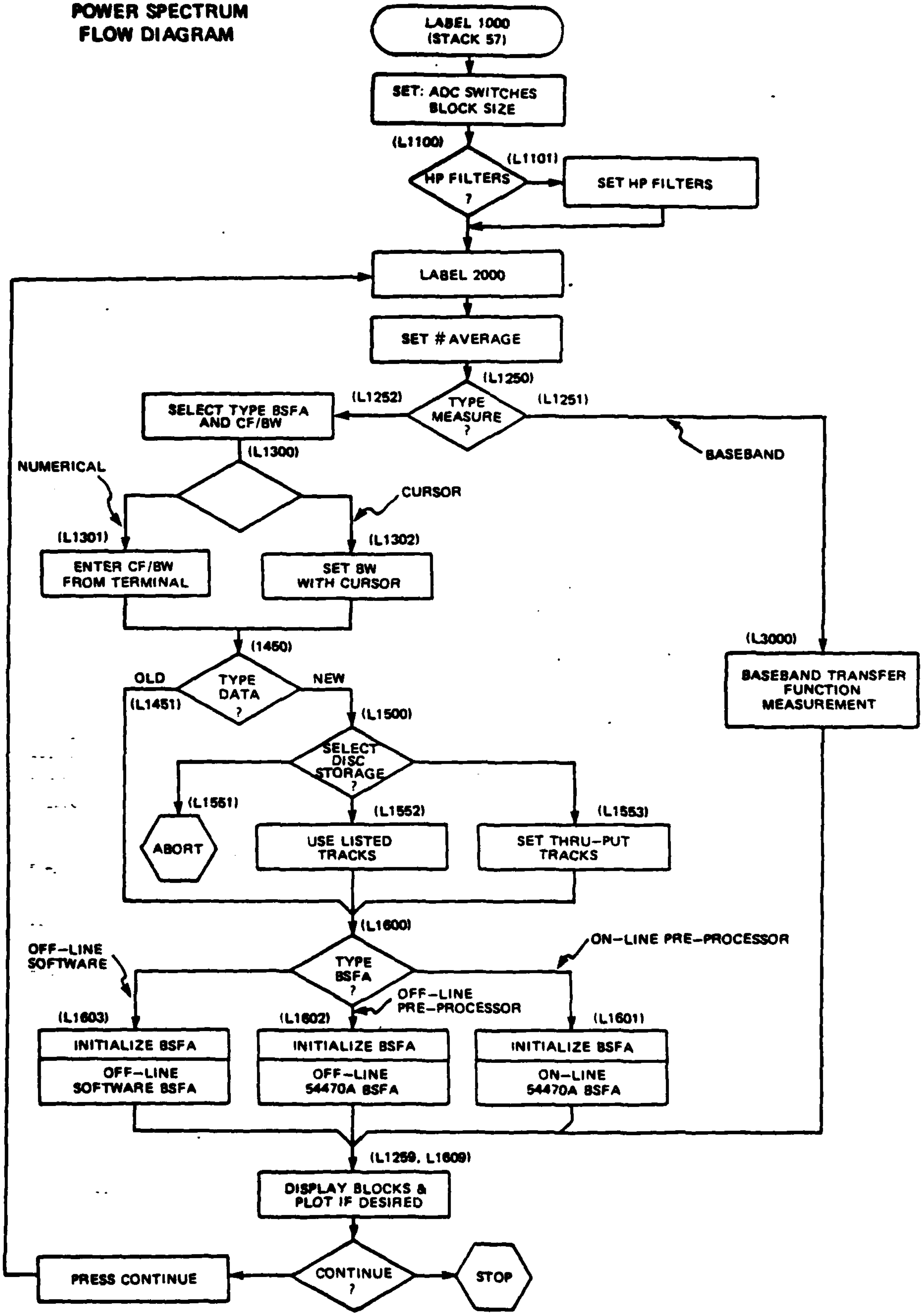
First record number = NR − (5 × last text buffer number)

Last record number = NR − (5 × first text buffer number) + 4

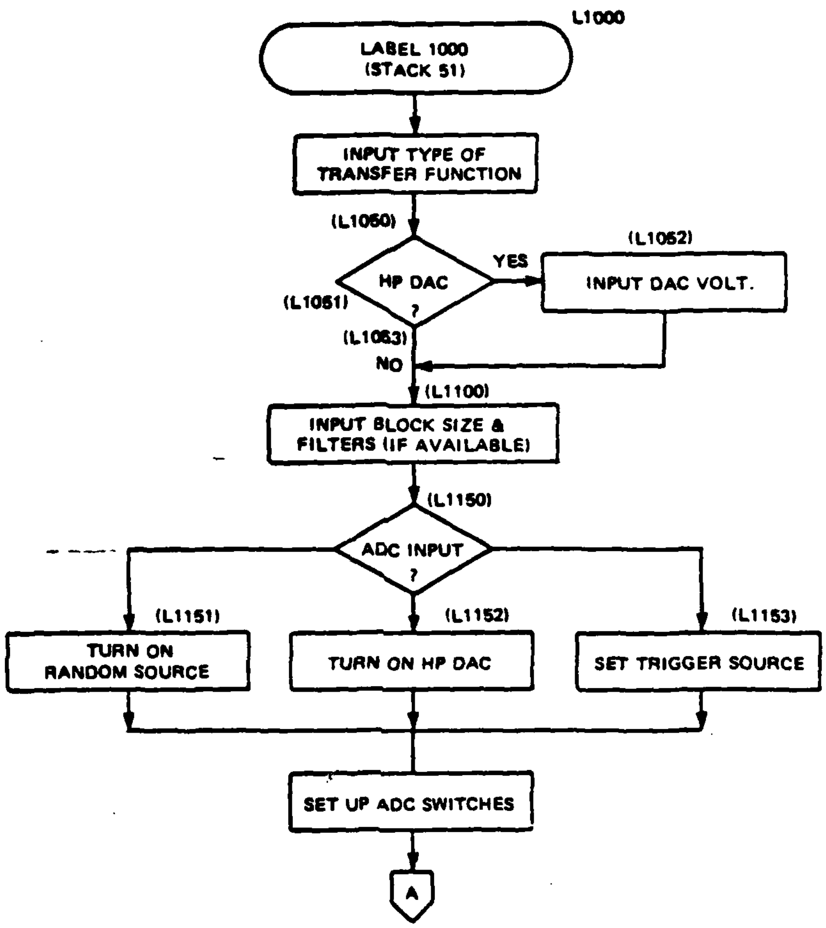
where NR = number of records in File 4.

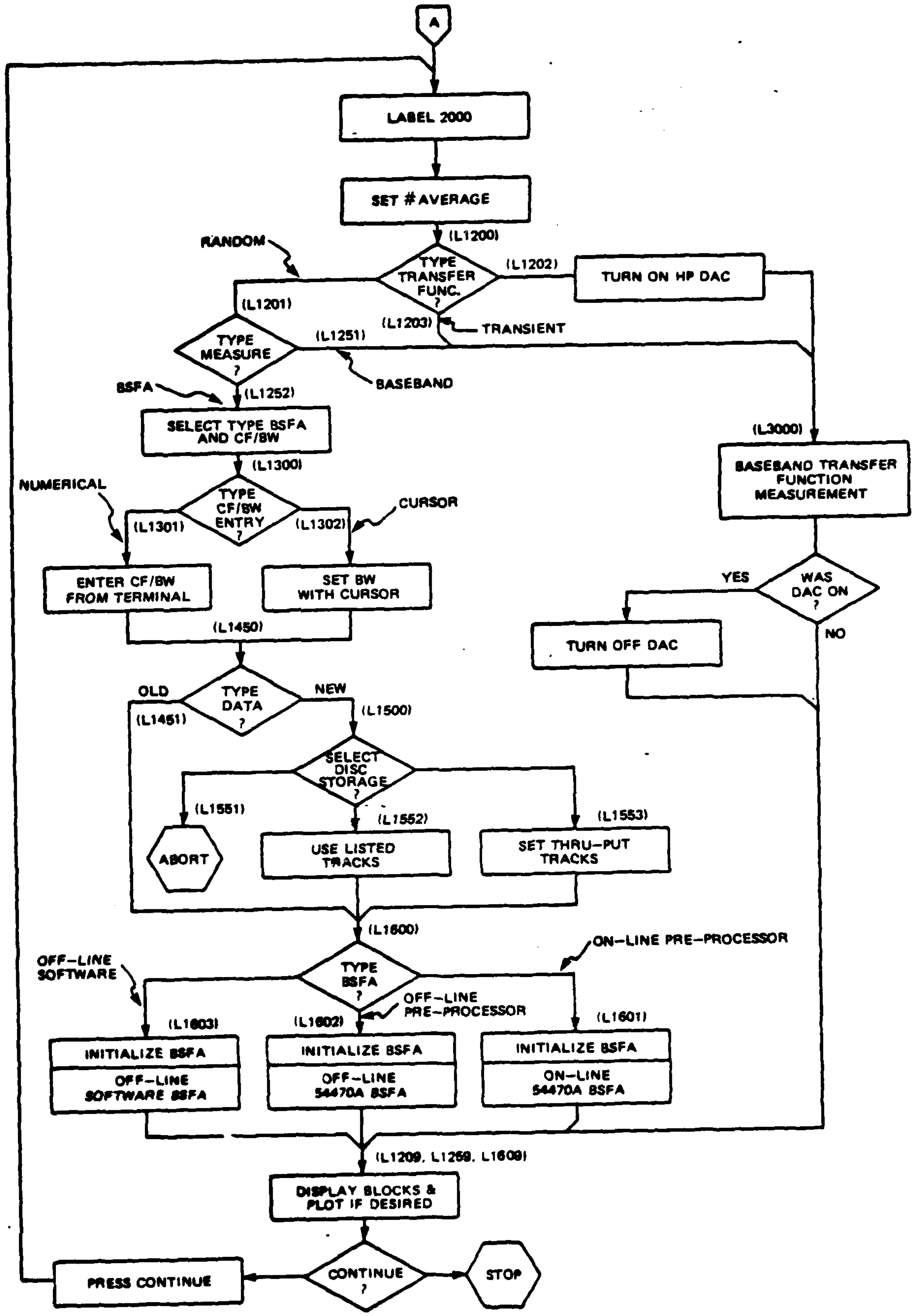
The allocations above should be kept in mind so the above records are not inadvertently altered or destroyed when using the Fourier system. Should you wish to alter the allocations, you will also have to modify the keyboard programs to reflect such changes.

POWER SPECTRUM FLOW DIAGRAM



TRANSFER FUNCTION
FLOW DIAGRAM




A
LABEL 2000
SET # AVERAGE
(L1200)
RANDOM
TYPE TRANSFER FUNC. ?
(L1202)
TURN ON HP DAC
(L1201)
(L1203)
TRANSIENT
TYPE MEASURE ?
(L1251)
BASEBAND
BSFA
(L1252)
SELECT TYPE BSFA AND CF/BW
(L1300)
(L3000)
BASEBAND TRANSFER FUNCTION MEASUREMENT
NUMERICAL
TYPE CF/BW ENTRY ?
CURSOR
(L1301)
(L1302)
ENTER CF/BW FROM TERMINAL
SET BW WITH CURSOR
YES
WAS DAC ON ?
NO
TURN OFF DAC
(L1450)
OLD
TYPE DATA ?
NEW
(L1451)
(L1500)
SELECT DISC STORAGE ?
(L1551)
(L1552)
(L1553)
ABORT
USE LISTED TRACKS
SET THRU-PUT TRACKS
(L1600)
ON-LINE PRE-PROCESSOR
OFF-LINE SOFTWARE
TYPE BSFA ?
OFF-LINE PRE-PROCESSOR
(L1603)
(L1602)
(L1601)
INITIALIZE BSFA
OFF-LINE SOFTWARE BSFA
INITIALIZE BSFA
OFF-LINE 54470A BSFA
INITIALIZE BSFA
ON-LINE 54470A BSFA
(L1209, L1259, L1609)
DISPLAY BLOCKS & PLOT IF DESIRED
PRESS CONTINUE
CONTINUE ?
STOP

```
L       0                       STACK 0
                                 Soft key jump directory
                                 "GOLD KEY" "Fn" causes jump to LABEL n
                                 in this stack. User can program the stack
                                 anywhere from there.
                                 Transfer Function and Power Spectrum
                                 are preprogrammed in. These may also
                                 be changed.

L       2                        F2   TRANSFER FUNCTION
J    1000      51                   Label 1000 in stack 51
L       5                        F5   POWER SPECTRUM
J    1000      57                   Label 1000 in stack 57
L       1                        F1   USER ASSIGNABLE
L       3                        F3   USER ASSIGNABLE
L       4                        F4   USER ASSIGNABLE
L       6                        F6   USER ASSIGNABLE
D                                Pause here if unassigned function called
J       6                          Loop if "CONTINUE" pressed
                                ==========================================
L     100                        PARAMETER ENTRY ROUTINE
Y R   2000                        Read user entry into variable 2000
Y IF  2000     1D   5   1         Check if entry >= lower limit
Y W     99       1                  Too small. Cue operator with range
Y P      1
Y W     98       1
Y P      2
J     100      -1                   and loop for new entry
L     101
Y IF  2000     2D   5  -1         Check if entry <= upper limit
Y W     99       1                  Too large. Cue operator with range
Y P      1
Y W     98       1
Y P      2
J     100      -1                   and loop for new entry
(                                 Return to calling program--entry in
                                    variable 2000, within specified range

L     109
.
                                ==========================================
```

```
L     -51                          STACK 51
L    1000                          TRANSFER FUNCTION PROGRAM
MS     37                           Recall previous variable parameters
MS     17
Y    5838      51                    Read text buffer #51
Y W      1      1                   Print messages 1 & 2
Y W      2      1
Y        1      1                   Set allowable range for user entry
Y -      2      3
J -   100       0                   Call user entry routine L100, stack 0
Y -     11   2000D
L -  1050                           BLOCK 1050
Y A+     0   1050       11D          Branch per value of variable 11
J       0D                              to L1051, 1052 or 1053
L    1051
L    1053
J    1059
L    1052
Y W      3      1
Y        1      3                    Parameter entry
Y -      2   9999                      Range: 0 - 1
J -   100       0                      Variable: 12
Y -     12   2000D
L -  1059                           END OF BLOCK 1050
Y W      5      1
BS    512                           Block size 512--user may change after pause
D                                   Pause for operator action
Y W      6      1
Y        1      0                   Parameter entry
Y -      2      1                     Range: 0 - 1
J -   100       0                     Variable: 14
Y -     14   2000D
L -  1100                           BLOCK 1100
Y A+     0   1101       14D
J       0D
L    1101
J    1109
L    1102
Y     100       0      -2            Set 2 filters--auto select mode
L    1109                           END OF BLOCK 1100
Y W      7      1
D                                   Pause for operator action
Y    5838      52
L    1150                           BLOCK 1150
Y A+     0   1150       11D          Branch per variable 11
J       0D                              to L1151, 1152 or 1153
L    1151
Y W      8      1
J    1159
L    1152
B        6    12D                    Fill DAC buffer and
B        6                              turn on DAC
J    1159
L    1153
Y W      9      1
L    1159                           END OF BLOCK 1150
Y W     10      1
RA                                  Analog input in "REPEAT" to monitor inputs
F
TL                                  Power spectrum (log) for user reference
J    2000       1       1           Jump to next stack and continue
.
```

```
L      -52                               STACK 52
L      2000                              LOOP POINT FOR TRANSFER FUNCTION
Y      5838       52
Y W      11        1
Y         1        1                      Parameter entry
Y -       2    32767                        Range: 1 - 32767
J -    100         0                        Variable: 15
Y        15    2000D
L -    1200                               BLOCK 1200 (ends in stack 54)
Y A+      0     1200       11D             Branch per variable 11
J        0D                                  to L1201, 1202 or 1203
L      1202
Y W      22        1
D                                          Pause for operator action
B         6                                Turn on DAC
J      3000        3        1              Subroutine call - baseband measurement
B                                          Turn off DAC
J      1209        2        1                then go to end of block 1200
L      1203
Y W      22        1
D                                          Pause for operator action
J      3000        3        1              Subroutine call - baseband measurement
J      1209        2        1                then go to end of block 1200
L      1201
Y W      12        1
Y         1        1                       Parameter entry
Y -       2        2                         Range: 1 - 2
J -     100        0                         Variable: 16
Y        16    2000D
L -    1250                                BLOCK 1250 (ends in stack 54)
Y A+      0     1250       16D              Branch per variable 16
J        0D                                   to L1251 or 1252
L      1251
Y W      22        1
D                                           Pause for operator action
J      3000        3        1               Subroutine call - baseband measurement
J      1259        2        1                 then go to end of block 1250
L      1252
Y W      13        1
Y         1        1                        Parameter entry
Y -       2        3                          Range: 1 - 3
J -     100        0                          Variable: 17
Y        17    2000D
Y -    5838       53
Y W      15        1
Y         1        1                        Parameter entry
Y -       2        2                          Range: 1 - 2
J -     100        0                          Variable 18
Y        18    2000D
  -
L      1300                                 BLOCK 1300 (ends in stack 53)
Y A+      0     1300       18D               Branch per variable 18
J        0D                                    to L1301 or 1302
L      1301
Y W      16        1
Y         1        1                         Parameter entry
Y -       2    32767                           Range: 1 - 32767
J -     100        0                           Variable: 19
Y        19    2000D
Y W      17        1
Y         1        1                         Parameter entry
Y A-      2      19D        1                  Range: 1 - (value of var 19 - 1
J       100        0                           Variable: 20
Y        20    2000D
J -    1309        1        1
L      1302
J      1303        1        1
```

STACK 53

```
L    -53
L    1303
Y W     18      1
/.   2000                          Cursor on. Cursor parameters to
                                     variables 2000 - 2002 (2001=frequency)
Y      2003   2001D                Variable 2003 gets 1st cursor frequency
Y W     19      1
/.   2000                          Cursor on, parameters to 2000 - 2002
/.     -1                          Cursor off
Y _    2004   2001D                Variable 2004 gets 2nd cursor frequency
L    1350                          BLOCK 1350
Y IF   2003   2004D   2  -2         If 1st cursor frequency > 2nd
Y _    2004   2003D                   then swap them
Y _    2003   2001D
L    1359                          END OF BLOCK 1350
Y A-   2000   2004D   2003D
Y        20   2000D                Variable 20 gets zoom bandwidth
Y T    2000
Y A+   2001   2003D   2000D
Y _      19   2001D                Variable 19 gets zoom center frequency
L    1400                          BLOCK 1400
Y IF     20     19D   1  -2         If bandwidth not < ctr freq
Y A-     20     19D   1               then bandwidth = ctr freq - 1
L    1409                          END OF BLOCK 1400
L    1309                          END OF BLOCK 1300 (from stack 52)
L    1450                          BLOCK 1450 (ends in stack 54)
Y A+      0   1450     17D         Branch per variable 17
J        0D                          to L1451, 1452 or 1453
L    1451
Y    5838      54
Y W     22      1
D                                  Pause for operator action
J    1459       1       1
L    1452
L    1453
Y W     20      1
Y         1     1                  Parameter entry
Y _       2     2                    Range: 1 - 2
J _   100       0                    Variable: 24
Y _      24   2000D
L    1500                          BLOCK 1500 (ends in stack 54)
Y    5838      54
Y A+      0   1500     24D          Branch per variable 24
J        0D                           to L1501 or 1502
L    1501
J    1509       1       1
L    1502
Y W     20      1
Y         1     1                   Parameter entry
Y _       2     3                     Range: 1 - 3
J _   100       0                     Variable: 2000 (temporary)
L    1550                           BLOCK 1550 (ends in stack 54)
Y A+      0   1550    2000D           Branch per variable 2000
J        0D                             to L1551, 1552 or 1553
L    1551
D                                     Pause & loop to here--abort
J    1551
L    1552
J    1554       1       1
L    1553
J    1555       1       1
```

```
L     -54                  STACK 54
L     1554
Y -     22     134              Variable 22 gets default start track
Y -     21      64              Variable 21 gets default # of records
J -   1559
L     1555
Y W     27       1
Y -      1       1              Parameter entry
Y -      2     197                Range: 1 - 197
J -    100       0                Variable: 22
Y       22    2000D             Variable 22 gets user's start track
Y A-    21     198    2000D     Variable 21 gets # of records left
L     1559                     END OF BLOCK 1550 (from stack 3)
MS      32     22D             Position throughput file to start track
Y W     22       1
D                              Pause for operator action
Y BS    13                     Variable 13 gets current block size
BS    2048                     Set block size to max for throughput
MS      22       2     21D     Perform ADC throughput
BS     13D                     Restore block size
Y W     21       1
L     1509                    END OF BLOCK 1500 (from stack 53)
L     1459                   END OF BLOCK 1450 (from stack 53)
L     1600                   BLOCK 1600
Y A+     0    1600     17D    Branch per variable 17
J       0D                      to L1601, 1602 or 1603
L     1601
Y       40     19D     20D    Initialize zoom--on line preprocessor
J     4000       2       1    Subroutine call--zoom measurement
Y       40       0            Reset zoom to baseband
J     1609                    Go to end of block 1600
L     1602
Y       43   19D   20D   22D  Initialize zoom--off line preprocessor
J     4500       2       1    Subroutine call--zoom measurement
Y       43       0            Reset zoom to baseband
J     1609                    Go to end of block 1600
L     1603
Y       41   19D   20D   22D  Initialize zoom--off line software
J     4500       2       1    Subroutine call--zoom measurement
Y       41       0            Reset zoom to baseband
L     1609                   END OF BLOCK 1600 (from stack 50)
L     1259                  END OF BLOCK 1250 (from stack 52)
L     1209                 END OF BLOCK 1209 (from stack 52)
Y     5838      54
Y W     23       1             Transfer function complete
Y W     24       1               Print instructions to operator
Y W     25       1
Y W     26       1
MS      37                     Save variable parameters
MS      27
D                              Pause for operator action
J     2000      -2       1     Loop to repeat transfer function
.                            END OF TRANSFER FUNCTION (except subroutines)
```

```
                                  STACK 55
L      -55                        BASEBAND TRANSFER FUNCTION SUBROUTINE
L      3000
Y      5838    55
Y         6     2      3          Check ADC input selecter. If not 2 channel
Y W        31     1                 inform operator
D                                   pause for operator to correct it and
J      3000    -1                   loop to check again.
CL        2                       Clear blocks needed for averaging
CL        3
CL        4
CL        5
L      3050                       BLOCK 3050
V A+       3   3050      11D       Branch per variable 11
J          0D    -1                  to L3051, 3052 or 3053
L      3051                        L3051 & 3052 equivalent--non-transient
L      3052
RA        0     3                  Analog input
H1        0                        Hann
H1        1
F         0     1                  Transform
CL        0     0                  Clear DC
CL        1     0
SP        0     2      2           Average spectra
#      3051   15D      0           Loop for specified # of averages
J      9050     7      1           Subroutine call - clear 2nd half block
CH        0     2      2           Compute transfer function
*         2    16                  Correct amplitude for hanning
:         2     3
*         3    16
:         3     3
J      3059    -1
L      3053                        L3053 transient signals
Y W        29     1                Instruct operator to impact on cue
L      3054
Y W        30     1                Cue with "beep"
RA        0     3                  Analog input
Y         5     0     -2           Check for overload--if so, cue again
F         0     1                  Transform
CL        0     0                  Clear DC
CL        1     0
SP        0     2      2           Average spectra
#      3054   15D      0           Loop for specified # of averages
J      9050     7      1           Subroutine call - clear 2nd half block
CH        0     2      2           Compute transfer function
L      3059                       END OF BLOCK 3050
TL        0                       Take logs of spectra
TL        2
TL        3
TL        4
<                                 Return to calling program
```

```
L      -56                          STACK 56
L     4000                          SUBROUTINE FOR ON LINE ZOOM TRANSFER FCN
Y     5038      55
Y        6       2       3           Check ADC input selecter If not 2 channels
Y W        31      1                    inform operator
D                                       pause for operator to correct it and
J     4000      -1                      loop to check again
CL       7                           Clear blocks needed for averaging
CL       8
CL       9
CL      10
L     4010
Y       45    5    1     8           Zoom, displaying Channel B power spectrum
SP       5       2       2           Average spectra
#     4010     15D       0           Loop for specified # of averages
CH       5       2       2           Compute transfer function
J     4200                           Subroutine call to move data
(                                    Return to calling program
                                    ========================================
L     4200                          SUBROUTINE TO MOVE DATA BLOCKS
X(       9                           Move data blocks from zoom area
X)       4                             to area for operator viewing
X(       8
X)       3
X(       7
X)       2
X(       6
X)       1
X(       5
TL       0                           Take logs of spectra
TL       2
TL       3
TL       4
(                                    Return to calling program
                                    ========================================
L     4500                          SUBROUTINE FOR OFF LINE ZOOM TRANSFER FCN
CL       7                           Clear blocks needed for averaging
CL       8
CL       9
CL      10
L     4510
Y       45    6    1     2           Zoom on Channel B
Y       45    5    1     1           Zoom on Channel A
D        8      4                    Display Channel B power spectrum
SP       5      2        2           Average spectra
#     4510     15D       0           Loop for specified # of averages
CH       5      2        2           Compute transfer function
J     4200                           Subroutine call to move data
(                                    Return to calling program
                                    ========================================
```

```
L       -57                         STACK 57
-      1000                         POWER SPECTRUM PROGRAM
MS       37                          Recall previous variable parameters
MS       17
Y      5838      51                  Read text buffer #51
Y W       4       1                  Print messages 4 & 5
Y W       5       1
BS      512                          Block size 512--user may change after pause
D                                    Pause for operator action
Y W       6       1
Y -       1       0                  Parameter entry
Y -       2       1                    Range: 0 - 1
J -     100       0                    Variable: 14
Y -      14    2000D
L      1100                          BLOCK 1100
Y A+      0    1101      14D
J        0D
L      1101
J      1109
L      1102
Y       100       0       -2          Set 2 filters--auto select mode
L      1109                          END OF BLOCK 1100
Y W       7       1
D                                    Pause for operator action
Y      5838      52
Y W      10       1
RA                                   Analog input in "REPEAT" to monitor inputs
F
TL                                   Power spectrum (log) for user reference
J      2000       1        1         Jump to next stack and continue
```

```
L     -58                          STACK 58
L     2000                         LOOP POINT FOR POWER SPECTRUM
Y     5830      52
Y W      11      1
Y _       1      1                  Parameter entry
Y _       2  32767                    Range: 1 - 32767
J      100       0                    Variable: 15
Y        15   2000D
Y G      12      1
Y _       1      1                  Parameter entry
Y _       2      2                    Range: 1 - 2
J      100       0                    Variable: 16
Y _      16   2000D
L _   1250                          BLOCK 1250 (ends in stack 60)
Y A+      0   1250  16D              Branch per variable 16
J        0D                            to L1251 or 1252
L     1251
Y W      22      1
D                                    Pause for operator action
J     3000       3      1            Subroutine call - baseband measurement
J     1259       2      1              then go to end of block 1250
L     1252
Y W      13      1
Y _       1      1                   Parameter entry
Y _       2      3                     Range: 1 - 3
J      100       0                     Variable: 17
Y _      17   2000D
Y _   5838      53
Y W      15      1
Y _       1      1                   Parameter entry
Y _       2      2                     Range: 1 - 2
J      100       0                     Variable: 18
Y _      18   2000D
L _   1300                           BLOCK 1300 (ends in stack 59)
Y A+      0   1300  18D               Branch per variable 18
J        0D                             to L1301 or 1302
L     1301
Y W      16      1
Y _       1      1                    Parameter entry
Y _       2  32767                      Range: 1 - 32767
J      100       0                      Variable: 19
Y        19   2000D
Y G      17      1
Y         1      1                    Parameter entry
Y A-      2     19D     1               Range: 1 - (value of var 19 - 1)
J      100       0                      Variable: 20
Y _      20   2000D
J     1309       1      1
L     1302
J     1303       1      1
```

```
L     -59                        STACK 59
L    1303
Y W      18        1
/.   2000                           Cursor on. Cursor parameters to
                                      variables 2000 - 2002 (2001=frequency)
Y       2003    2001D               Variable 2003 gets 1st cursor frequency
Y B      19        1
/.   2000                           Cursor on, parameters to 2000 - 2002
/.     -1                           Cursor off
Y _     2004    2001D               Variable 2004 gets 2nd cursor frequency
L    1350                           BLOCK 1350
Y IF    2003    2004D   2  -2        If 1st cursor frequency > 2nd
Y _     2004    2003D                  then swap them
Y _     2003    2001D               END OF BLOCK 1350
L    1359
Y A-    2000    2004D   2003D
Y _       20    2000D               Variable 20 gets zoom bandwidth
Y T     2000
Y A+    2001    2003D   2000D
Y _       19    2001D               Variable 19 gets zoom center frequency
L    1400                           BLOCK 1400
Y IF      20     19D    1  -2        If bandwidth not < ctr freq
Y A-      20     19D    1              then bandwidth = ctr freq - 1
L    1409                           END OF BLOCK 1400
L    1309                           END OF BLOCK 1300 (from stack 58)
L    1450                           BLOCK 1450 (ends in stack 60)
Y A+       0    1450     17D        Branch per variable 17
J       0D                            to L1451, 1452 or 1453
L    1451
Y    5838        54
Y W      22        1
D                                   Pause for operator action
J    1459        1      1
L    1452
L    1453
Y W      20        1
Y          1       1                Parameter entry
Y _        2       2                  Range: 1 - 2
J     100        0                    Variable: 24
Y _       24    2000D
L    1500                           BLOCK 1500 (ends in stack 60)
Y    5838        54
Y A+       0    1500     24D         Branch per variable 24
J       0D                             to L1501 or 1502
L    1501
J    1509        1      1
L    1502
Y W      20        1
Y          1       1                 Parameter entry
Y _        2       3                   Range: 1 - 3
J     100        0                     Variable: 2000 (temporary)
L    1550                            BLOCK 1550 (ends in stack 60)
Y A+       0    1550   2000D          Branch per variable 2000
J       0D                              to L1551, 1552 or 1553
L    1551
D                                     Pause & loop to here--abort
J    1551
L    1552
J    1554        1      1
L    1553
J    1555        1      1
.
```

```
L     -60                  STACK 60
L    1554
Y _     22     134              Variable 22 gets default start track
Y -     21      64              variable 21 gets default # of records
J -  1559
L    1555
Y W     27       1
Y -      1       1              Parameter entry
Y -      2     197                Range: 1 - 197
J -   100        0                Variable: 22
Y       22   2000D              Variable 22 gets user's start track
Y A-    21     198    2000D     Variable 21 gets # of records left
L    1559                      END OF BLOCK 1550 (from stack 59)
MS      32     22D             Position throughput file to start track
Y W     22       1
D                              Pause for operator action
Y BS    13                     Variable 13 gets current block size
BS   4096                      Set block size to max for throughput
MS      22       1     21D     Perform ADC throughput
BS     13D                     Restore block size
Y W     21       1
L    1509                    END OF BLOCK 1500 (from stack 59)
L    1459                   END OF BLOCK 1450 (from stack 59)
L    1600                   BLOCK 1600
Y A+     0    1600     17D   Branch per variable 17
J       0D                     to L1601, 1602 or 1603
L    1601
Y       40    19D   20D      Initialize zoom--on line preprocessor
J     4000      1     1      Subroutine call--zoom measurement
Y       40      0            Reset zoom to baseband
J     1609                   Go to end of block 1600
L     1602
Y       43    19D   20D   22D  Initialize zoom--off line preprocessor
J     4500      1     1      Subroutine call--zoom measurement
Y       43      0            Reset zoom to baseband
J     1609                   Go to end of block 1600
L     1603
Y       41    19D   20D   22D  Initialize zoom--off line software
J     4500      1     1      Subroutine call--zoom measurement
Y       41      0            Reset zoom to baseband
L     1609                  END OF BLOCK 1600
L     1259                 END OF BLOCK 1250 (from stack 58)
Y     5838     54
Y W     23      1          Power spectrum complete
Y W     25      1            Print messages to operator
Y W     26      1
MS      37                 Save variable parameters
MS      27
D                          Pause for operator action
J     2000     -2     1    Loop to repeat power spectrum
.                         END OF POWER SPECTRUM (except subroutines)
```

```
L     -61                         STACK 61
L     3000                        BASEBAND POWER SPECTRUM SUBROUTINE
Y     5838      55
Y        6       1      3          Check ADC input selector. If not 1 channel
Y W        32      1                 inform operator
D                                    pause for operator to correct it and
J     3000      -1                   loop to check again
CL       1                         Clear block needed for averaging
L     3010
RA       0       1                 Analog input, displaying average
H1       0                         Hann
F                                  Transform
CL       0       0                 Clear DC
SP       0                         Average spectrum
#     3010      15D      0         Loop for specified # of averages
J     9055       1      1          Subroutine call - clear 2nd half block
#        1      16                 Hanning correction for broadband noise
:        1       3
X(       1                         Load average to block 0
TL       0                         Take log
(                                  Return to calling program
L     4000                        ========================================
Y     5838      55                 SUBROUTINE FOR ON LINE ZOOM POWER SPECTRUM
Y        6       1      3
Y W        32      1               Check ADC selector. If not 2 channels
D                                    inform operator
J     4000      -1                   pause for operator to correct it and
CL       2                           loop to check again
L     4010                         Clear block needed for averaging
Y       45       1      1            2
SP       1                         Zoom, displaying power spectrum
#     4010      15D      0         Average spectrum
X(       2                         Loop for specified # of averages
TL                                 Load average to block 0
(                                  Take log
L     4500                         Return to calling program
CL       2                        ========================================
L     4510                        SUBROUTINE FOR OFF LINE ZOOM POWER SPECTRUM
Y       45       1      1          Clear block needed for averaging
D        2       4
SP       1                         Zoom
#     4510      15D      0         Display average (1 sweep)
X(       2                         Average
TL                                 Loop for specified # of averages
(                                  Load average to block 0
.                                  Take log
                                   Return to calling program
                                  ========================================
```

```
L     -62                        STACK 62
L    9050                        CLEAR 2ND HALF BLOCK SUBROUTINE
Y -      29    9057               Set return label value
J -  9056      -1
L    9057                         Return label
CL      4      25D      26D       Clear last half block 4
CL      5      25D      26D       Clear last half block 5
J    9059      -1
L    9055                         Entry pt. Pwr Spec pgm
Y -      29    9058               Set return label value
J -  9056      -1
L    9058                         Return label
CL      1      25D      26D       Clear last half block 1
J    9059      -1
L    9056
Y A+     0     9051      14D      Was HP filter selected?
J       0D      -1                No, Gto 9051
L    9052                         Yes
Y BS    13                        Get current blocksize
Y :      26     13D               Store Bs/2 in variable 26
Y :      25     26D               Store Bs/4 in variable 25
J      29D      -1                Indirect return
L    9051
L    9059                         End of pgm 9050&9055
<                                 Return to calling program
.
```

Text buffer messages for Transfer Function and Power Spectrum programs

```
  BUFFER #   MESSAGE #

      51         1
HP TRANSFER FUNCTION PROGRAM

      51         2
SELECT EXCITATION TYPE
  51=RANDOM - BASEBAND OR ZOOM
  2=HP DAC - BASEBAND ONLY
  3=TRANSIENT - BASEBAND ONLY

      51         3
INPUT DESIRED DAC OUTPUT IN MV

      51         4
HP POWER SPECTRUM PROGRAM

      51         5
SET ADC FREQUENCY RANGE AS DESIRED
   (SAMPLE MODE & MULTIPLIER)
SET ADC TRIGGER TO "FREE RUN"
CHANGE BLOCK SIZE IF DESIRED
PRESS "CONTINUE" WHEN READY

      51         6
ARE HP FILTERS INSTALLED?
  0=NO, 51=YES
```

```
    51        7
SET KEYBOARD REPEAT/SINGLE SWITCH
 TO "REPEAT"
PRESS "CONTINUE" WHEN READY


  UPPER 51 LIMIT = 98


    51        99
ENTRY OUT OF RANGE-PLEASE REENTER
  LOWER LIMIT =
  PRESS CONTINUE WHEN READY


    52         8
TURN ON RANDOM EXCITATION SOURCE


    52         9
SET TRIGGER SOURCE AS DESIRED
IMPACT STRUCTURE REPEATEDLY


    52         10
SET OVERLOAD VOLTAGES AND TRIGGER
 LEVELS FOR SIGNAL AMPLITUDES
MOVE REPEAT/SINGLE SWITCH TO
 "SINGLE" WHEN READY.  IF SOURCE
 IS NOT IN FREE RUN, TRIGGER THE
 SYSTEM AGAIN TO CONTINUE.


    52         11
ENTER NUMBER OF AVERAGES DESIRED


    52         12
ENTER MEASUREMENT TYPE
  1=BASEBAND
  52=ZOOM


    52         13
ENTER ZOOM MEASUREMENT MODE
  1=ON LINE, PREPROCESSOR
  52=OFF LINE, PREPROCESSOR
  3=OFF LINE, SOFTWARE
```

```
       52       14
ZOOM NOT APPROPRIATE WITH HP DAC          Beeps to cue operator
 BASEBAND MEASUREMENT WILL BE MADE


       53       15
HOW WILL YOU SPECIFY ZOOM BANDWIDTH?
  1=NUMERIC ENTRY - CTR FREQ & BW
  2=CURSOR - ON PRIOR MEASUREMENT


       53       16
ENTER CENTER FREQUENCY


       53       17
ENTER BANDWIDTH


       53       18
MOVE CURSOR TO START FREQUENCY
 PRESS "VALUE" (SWITCH REGISTER 11)


       53       19
MOVE CURSOR TO END FREQUENCY
 PRESS "VALUE"


       53       20
ANALYZE OLD OR NEW DATA?
  1=OLD (FROM THROUGHPUT FILE)
  2=NEW


       54       21
THROUGHPUT COMPLETED


       54       22
PRESS "CONTINUE" FOR MEASUREMENT


       54       23
MEASUREMENT COMPLETE


       54       24
TO DISPLAY RESULTS, PRESS:
  "DISPLAY" "0"  LOG TRANSFER FCN
  "DISPLAY" "1"  COHERENCE
  "DISPLAY" "2"  INPUT POWER SPECT
```

```
 "DISPLAY" "3"  OUTPUT POWER SPECT
 "DISPLAY" "54"  CROSS POWER SPECT


      54       25
TO COPY DISPLAY ON TERMINAL:
 PUT TERMINAL IN GRAPHICS MODE
 PRESS "GOLD KEY" "PLOT"


      54       26
TO MAKE ANOTHER MEASUREMENT:
 PUT TERMINAL IN ASCII MODE
 PRESS "CONTINUE"


      54       27
ENTER STARTING TRACK FOR THROUGHPUT


      54       28
THROUGHPUT WILL USE TRACKS
 135 THROUGH 198 ON THE LOWER
 (FSDS) DISC. IS THIS OK?
  1=NO - ABORT
  2=YES - PROCEED
  3=NO - ASK ME FOR TRACK #


      55       29
IMPACT STRUCTURE ON CUE (BEEP)
 FOR EACH AVERAGE


      55       30
                                          Beeps to cue operator
      55       31
SET ADC INPUT SELECTOR TO "AB"            Beeps to cue operator
 PRESS "CONTINUE" WHEN READY


      55       32
SET ADC INPUT SELECTOR TO "A"             Beeps to cue operator
 PRESS "CONTINUE" WHEN READY
```

APPENDIX C

CALIBRATION DATA

ACCELEROMETER MOUNTING WAX
Model 080A24

PCB PIEZOTRONICS

Petro-Wax functions to transfer motion from the test object to the sensor. It is used to couple the sensor directly to the test object. It is a convenient, temporary mounting replacement for studs and permanent adhesives.

An elastic interface structure with heavy damping, it forms quickly to irregular surfaces to facilitate easy mounting of sensors. This pliable wax enables the sensor to be mounted in nearly any convenient spacial coordinate system.

In conjunction with the sensor, the wax forms a heavily damped spring-mass system. The frequency response is a function of transducer mass, mounting area, depth of wax, and test temperature. As the amount of wax at the interface of the sensor and test object increases, the first resonance of the system decreases, which limits the frequency response of the fixturing (see graphs). This mounting technique is primarily for use at room temperature. The wax cannot be used effectively at high or low temperatures.

How to use:
(1) To insure a secure and valid fixture, be certain all surfaces are free of oil and dirt.
(2) Apply the wax directly to the base of the transducer or to the adhesive mounting base. The amount of wax used depends on your individual application. Use of the adhesive mounting base helps keep the transducer clean.
(3) Press the sensor firmly against the test structure to insure secure mounting and as little wax at interface as possible. This provides the best frequency response.
(4) Procede with measurement.

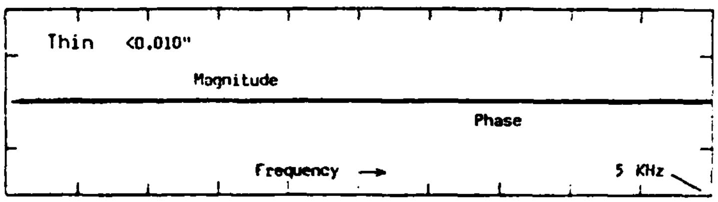
PETRO-WAX is available in quantity from: Katt & Associates
P.O. Box 98269
Pittsburgh, PA 15227
(412) 885-5727

MODEL NO. 308B

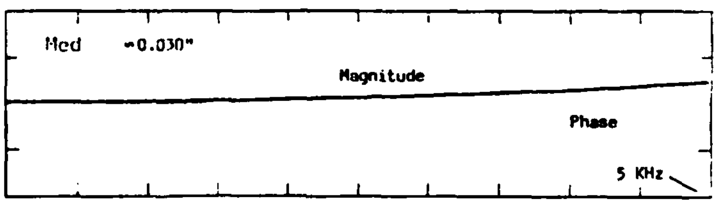
Horizontal Scale 5 000 Hz

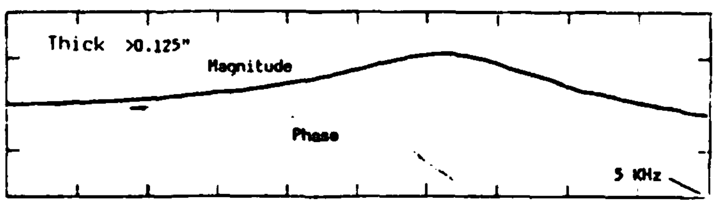
Mag. : vert. scale 10 db/div

Phase: vert. scale 50 °/div



FREQ (Hz)	Thin DEV (%)	Med DEV (%)	Thick DEV (%)
20	-1	-1	-1
50	0	0	0
100	0	0	0
200	0	1	1
500	1	2	3
1 000	1	3	11
2 000	2	10	276
5 000	10	74	-27
10 000			
20 000			





PCB PIEZOTRONICS, INC. 3425 WALDEN AVENUE DEPEW NEW YORK 14043-2495 TELEPHONE 716-684-0001 TWX 710-263-1371

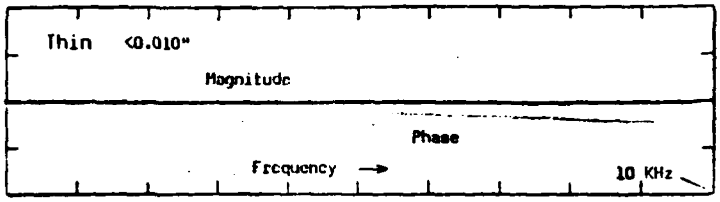
MODEL NO. 302A

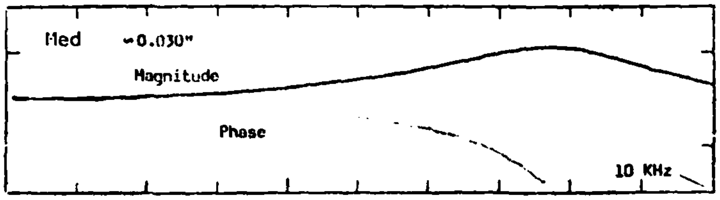
Horizontal Scale 10 000 Hz

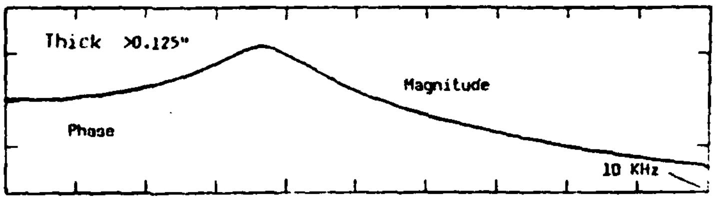
Mag. : vert. scale 10 db/div

Phase: vert. scale 50 °/div

	Thin	Med	Thick
FREQ (Hz)	DEV (%)	DEV (%)	DEV (%)
20	-1	-1	-1
50	0	0	-1
100	0	0	0
200	0	0	0
500	1	1	2
1 000	1	2	8
2 000	1	7	41
5 000	1	62	35
10 000	11	56	-450
20 000			







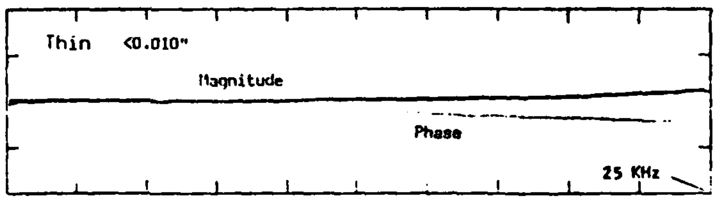
MODEL NO. 303A

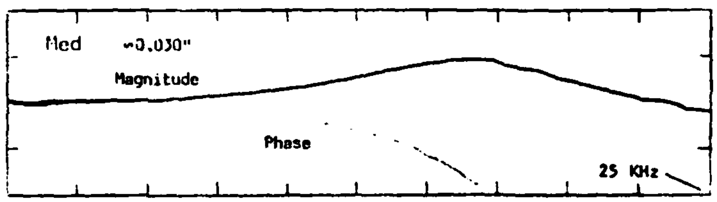
Horizontal Scale 25 000 Hz

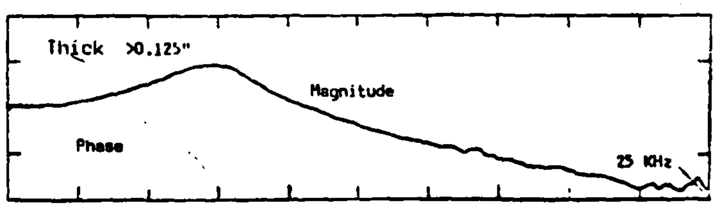
Mag. : vert. scale 10 db/div

Phase: vert. scale 50 °/div

	Thin	Med	Thick
FREQ (Hz)	DEV (%)	DEV (%)	DEV (%)
20			
50	-1	-1	-1
100	0	0	0
200	0	0	0
500	1	1	1
1 000	1	1	2
2 000	0	3	8
5 000	0	11	48
10 000	1	90	26
20 000	15	-16	-546







PCB CALIBRATION CERTIFICATE
IMPACT FORCE HAMMER

Model No. 086B03
Transducer Model No. —
Transducer Serial No. 269
Hammer Calibrator: PCB Model 904A
Pendulous Mass 0.72 lb (326 gm) including accelerometer
Date: 3-23-83
Initials: P.J.

PCB PIEZOTRONICS, INC.

Customer: US Naval Postgraduate School
Invoice No: 22416

Basic Force Transducer Sensitivity 10.60 mV/lb (reference)
(for stationary installations)

Reference Accelerometer Sensitivity 10.12 mV/g (302A S/N 2531)

Ratio: Force Transducer Sensitivity/Accelerometer Sensitivity 1.05 / 1.0?
(from test of mass impacting stationary hammer)

HAMMER SENSITIVITY (3) (with 2.7 gm Al/Plastic, Al/Steel, Al/Rubber Tips.

Configuration	with Steel Extender	with Al. Extender	with No Extender
Ratio: Force/Acceleration Sensitivity (2)	1.026		0.972
Hammer Sensitivity mV/lb	10.38		9.84
Difference: (1) (%)	-2.1%		-7.2%

NOTES: (1) Difference from reference sensitivity of force transducer

(2) In transfer fuction testing, the important factor is the ratio of sensitivities.

(3) Because of normal behavior of the hammer structure, the apparent sensitivity of the hammer in motion differs from the stationary calibration of the force transducer. It is less by a factor proportional to the ratio of the mass of the impact cap and seismic distributing mass in the transducer to the total mass of the hammer structure. Using a heavier hammer head or installing the force transducer on the structure only changes the problem. A heavier hammer head tends to penetrate the test object or cause multiple bouncing. When mounted on the test object, the inertial mass in the transducer causes it to act as an accelerometer sensing motion of the test object.

Customer US Naval Postgraduate School

Order No. N6227183 F 0446

PCB PIEZOTRONICS

CALIBRATIO[illegible] [illegible]TA
for
I. C. P. ACCELEROMETER
(per I S A S37.2)

Model No. 303A03
Serial No. 5133
Range 500
Max Input 2000
Max Temp 200

[illegible] hammer kit

1. VOLTAGE SENSITIVITY ...... $\boxed{10.37 \text{ mv/g}}$ @ 100 Hz, 8 g's PK
2. MAXIMUM TRANSVERSE SENSITIVITY 1.7 percent
3. RESONANT FREQUENCY .... 76 KHz
4. DISCHARGE TIME CONSTANT ..... 1.1 seconds
5. OUTPUT BIAS LEVEL .... 8.6 Volts
6. FREQUENCY RESPONSE:

Freq. Hz		10	30	50	100	300	500	1000	3000	5000	7000	10,000
Deviation %		-3.3	-2.0	-0.8	0	+0.7	+1.0	+1.3	+2.0	+2.4	+2.1	+3.3

Calibration traceable to NBS through project no. 737/229322

PCB PIEZOTRONICS, INC.
3425 WALDEN AVENUE
DEPEW, NEW YORK 14043

date 3-9-83

by P. Jennings

Customer US Naval Postgraduate School

Order No. N6227183 F 0446

PCB PIEZOTRONICS

CALIBRATION DATA
for
I. C. P. ACCELEROMETER
(per I S A S37.2)

Model No. 302A02
Serial No. 7531
Range 500
Max Input 2000
Max Temp 250

[illegible] hammer kit

1. VOLTAGE SENSITIVITY ...... $\boxed{10.12 \text{ mv/g}}$ @ 100 Hz, 8 g's PK
2. MAXIMUM TRANSVERSE SENSITIVITY 0.5 percent
3. RESONANT FREQUENCY .... >35 KHz
4. DISCHARGE TIME CONSTANT ..... 0.8 seconds
5. OUTPUT BIAS LEVEL .... 11.8 Volts
6. FREQUENCY RESPONSE:

Freq. Hz		10	30	50	100	300	500	1000	3000	5000		
Deviation %		-1.0	-0.6	-0.3	0	0.0	+0.3	+0.6	+2.2	+6.6		

Calibration traceable to NBS through project no. 737/229322

PCB PIEZOTRONICS INC
3425 WALDEN AVENUE
DEPEW, NEW YORK 14043

date 2-21-83

by P. Jennings

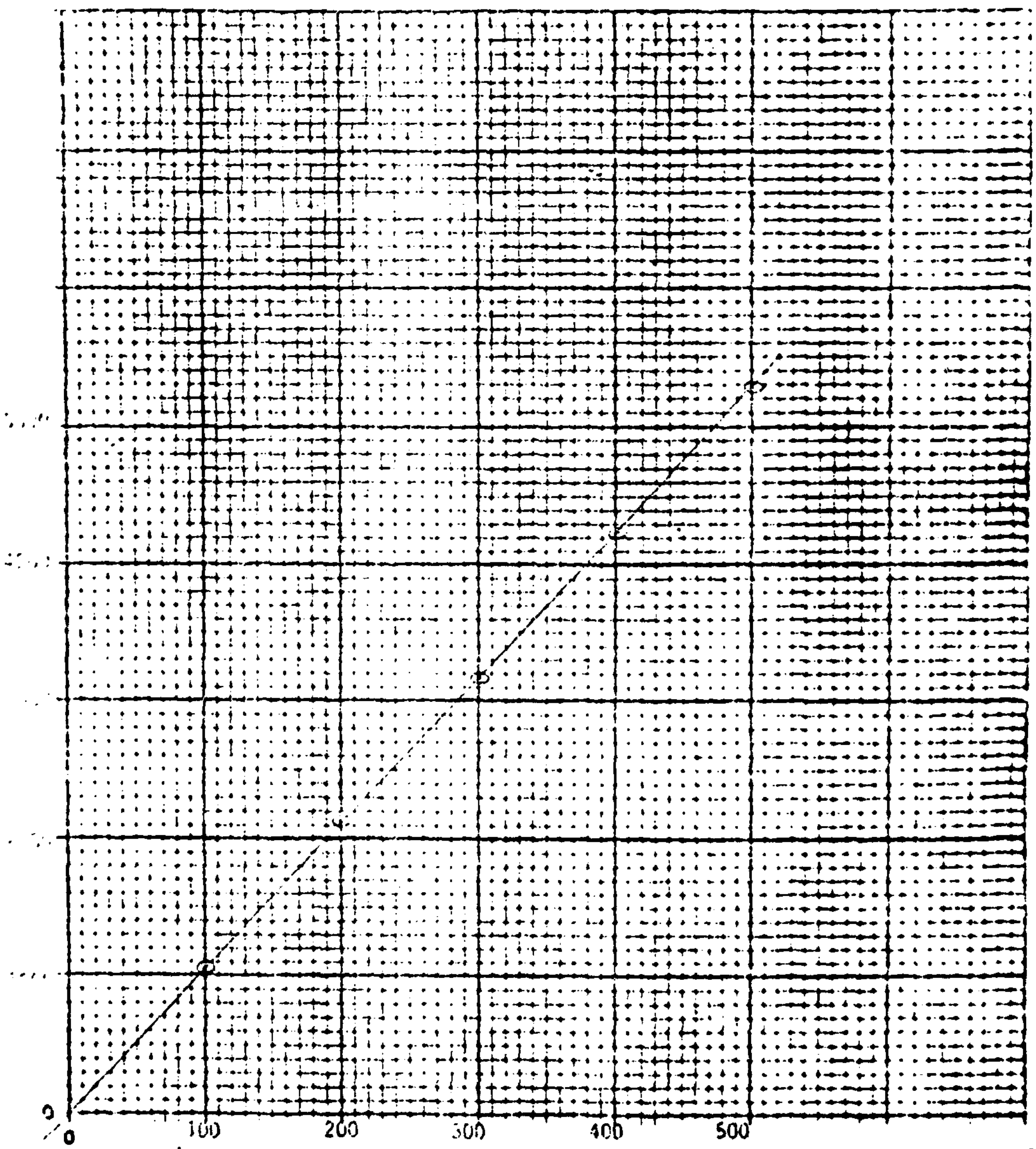
I.C.P. TRANSDUCER DATA

PIEZOTRONICS INC
P.O. BOX 33
BUFFALO, NEW YORK 14225

Model 086B03
S N 269
Average Sensitivity* 10.60 mv LP
Linearity ≤1% F.S.

Cal. Range 0-500 LBS.
Input Time Constant 2000 Sec
Rise Time 10 μ Sec
Natural Frequency 31 KHz
Output Impedance <100 Ohms

By
Date 9-27-83
*By comparison with reference Standard



INPUT pounds

CUSTOMER US Naval Postgraduate School
P.O. NO. N62271-83-F-0446

50 ft lb. hammer kit

PCB CALIBRATION CERTIFICATE

IMPULSE FORCE HAMMER.

PCB PIEZOTRONICS, INC.

Model No. 086B80 Kit No. GK291586 Customer:

Serial No. 235 Naval Postgraduate School

Range 0 - 50 lb

Linearity error < 2.0 % Invoice No.:

Discharge Time Constant 100 s A2022

Output Impedance 100 ohms

Output Bias 12.2 volts

Traceable to NBS through 737/229322

Initials RckL Date: 4/8/89

Force Accelerometer: Model No. 208B, Serial No. 2974, Sens. 572 mV/g

Pendulous Test Mass — lb (— gram) including accelerometer

Hammer Sensitivity:

CONFIGURATION Tip / Extender	STEEL / NONE	VINYL / STEEL	
SCALING FACTOR (SENSITIVITY RATIO)	.198	.124	
HAMMER mV/lb	113.3	70.9	
SENSITIVITY (mV/N)	25.5	15.9	

NOTES:

1. The sensitivity ratio (Sa/Sf) is the scaling factor for converting structural transfer measurements into engineering units. Divide results by this ratio.

2. Each specific hammer configuration has a different sensitivity. The difference is a constant percentage, which depends on the mass of the cap and tip assembly relative to the total mass of the head. Calibrating the specific hammer structure being used automatically compensates for mass effects.

Effective mass [—] with 302A07 attached and vinyl capped plastic tip.

tomer Naval Postgraduate School ler No. N62271 83M 1103	PCB PIEZOTRONICS 50 ft lb hammer kit **CALIBRATION DATA** for **I. C. P. ACCELEROMETER** (per I S A S37.2)	Model No. 309A Serial No. 228 Range 1000 g's Max Input 1000 g's Max Temp 150 °F

1. VOLTAGE SENSITIVITY ...... 5.68 mv/g @ 100 Hz, 8 g's PK
2. MAXIMUM TRANSVERSE SENSITIVITY 2.8 percent
3. RESONANT FREQUENCY .... 7120 KHz
4. DISCHARGE TIME CONSTANT ..... 0.2 seconds
5. OUTPUT BIAS LEVEL .... 8.7 Volts
6. FREQUENCY RESPONSE:

Freq. Hz		10	30	50	100	300	500	1000	3000	5000	7000	10000
Deviation %		-4.8	-2.6	-1.1	0	+0.9	+1.4	+1.9	+1.9	+3.2	+3.8	+5.0

Calibration traceable to NBS through project no. 737/229322

PCB PIEZOTRONICS, INC.
3425 WALDEN AVENUE
DEPEW, NEW YORK 14043

date 3-8-83
by [illegible]

tomer Naval Postgraduate School er No. N62271 83M 1103	PCB PIEZOTRONICS 50 ft-lb hammer kit **CALIBRATION DATA** for **I. C. P. ACCELEROMETER** (per I S A S37.2)	Model No. 303A03 Serial No. 5164 Range 500 g's Max Input 2000 g's Max Temp 200 °F

1. VOLTAGE SENSITIVITY ...... 11.06 mv/g @ 100 Hz, 8 g's PK
2. MAXIMUM TRANSVERSE SENSITIVITY 1.9 percent
3. RESONANT FREQUENCY .... 78 KHz
4. DISCHARGE TIME CONSTANT ..... 1.0 seconds
5. OUTPUT BIAS LEVEL .... 8.6 Volts
6. FREQUENCY RESPONSE:

Freq. Hz		10	30	50	100	300	500	1000	3000	5000	7000	10,000
Deviation %		-2.0	-1.5	-1.0	0	+0.7	+1.0	+1.6	+2.4	+2.4	+2.6	+3.1

Calibration traceable to NBS through project no. 737/229322

PCB PIEZOTRONICS, INC.
3425 WALDEN AVENUE
DEPEW, NEW YORK 14043

date 3-21-83
by [illegible]

I.C.P. TRANSDUCER DATA

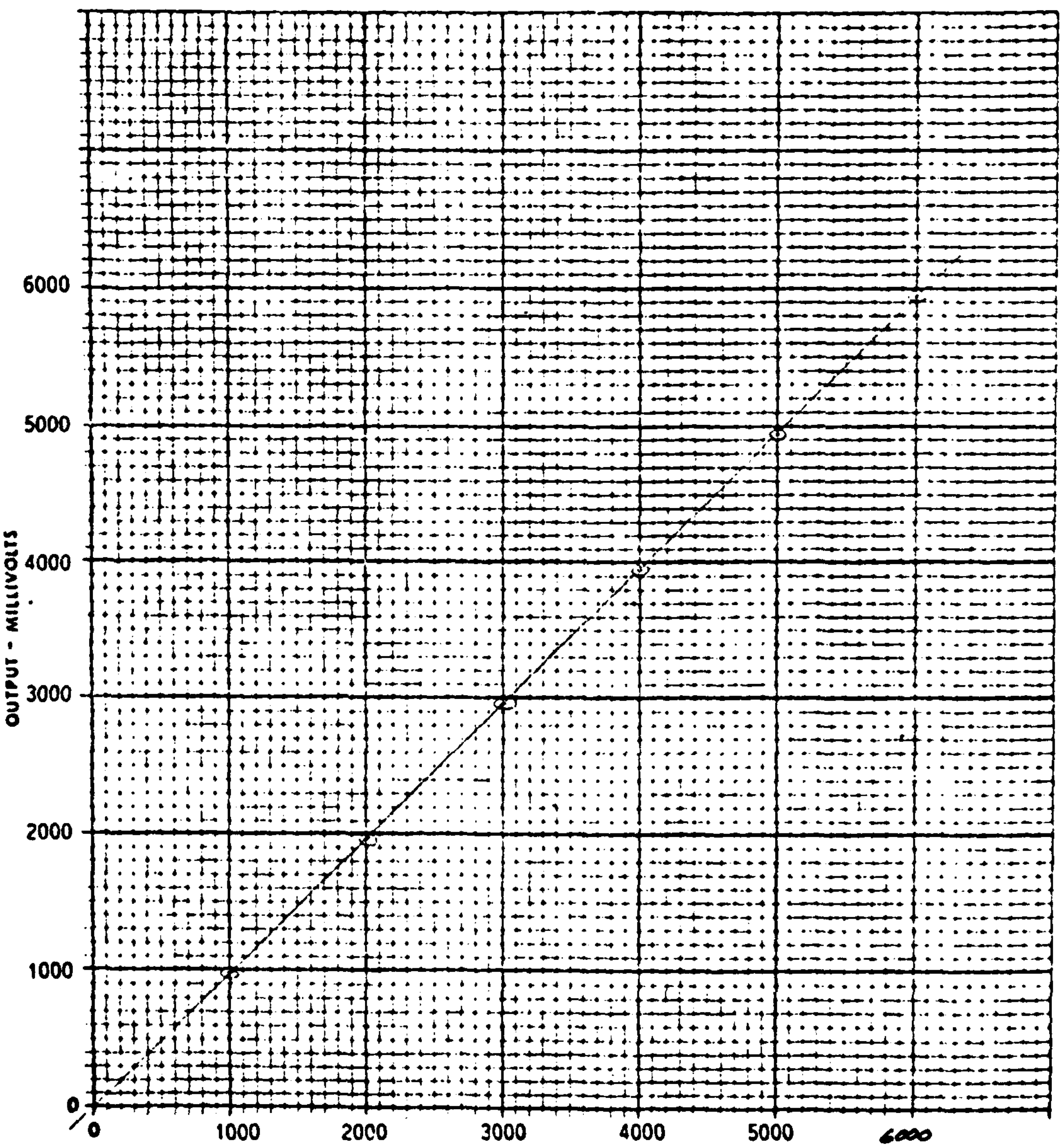
PIEZOTRONICS INC.
P.O. BOX 33
BUFFALO, NEW YORK 14225

Model: 222A
S/N: 267
Average Sensitivity*: 0.99 mv/psi/LB
Linearity: ∠1.0 %F.S.

Cal. Range: 0–6000 LBS.
Input Time Constant: 2000 Sec
Rise Time: 10 μ Sec
Natural Frequency: 50 KHz
Output Impedance: <100 Ohms

By: T. Cieplinski
Date: 5-23-83

*By comparison with reference Standard per ISA S37.10



INPUT LBS

CUSTOMER NAVY
PO NO N62271-83-M-1823

APPENDIX D

LOCALLY GENERATED USER KEYBOARD PROGRAMS

The locally generated keyboard programs presented in the next six pages allow the use of impulse technique or random excitation while utilizing the Modal package of the HP-5451C Fourier Analyzer. Each program and subprogram is identified by the first line of the program listing. Program number 1 (identified by the -1 on line 1) is the control program, and from this program subprograms 50, 51, 52, 53, 54, 58 and 59 are called as needed.

All eight programs are automatically loaded into the computer memory when the following command is executed, as discussed in Chapter V, step number 35,

[JUMP] 0 1 [ENTER]

```
  1 L       -1
  5 L        0
  9 L       10
 13 Y     5830      1
 18 Y _       32       1
 24 Y _       30       0
 30 Y W       11       1
 36 Y W       12       1
 42 Y _        1       0
 48 Y _        2       1
 54 J      100      59
 59 Y _        1   20000
 65 Y IF       1       1        2        -2
 73 Y      100       0       -2
 79 J        9      -1
 84 Y      100      99       -2
 90 L        9
 94 J      100      58
 99 L       11
103 Y W       16       1
109 Y _        1       1
115 Y _        2     500
121 J      100      59
126 Y _       21   20000
132 Y W       13       1
138 Y _        1       0
144 Y _        2       1
150 J      100      59
155 Y _        1   20000
161 Y IF       1       0        2         0
169 J      510      51
174 J       12      -1
179 Y IF      43       1        2         0
187 J      530      53
192 J       12      -1
197 J      500      50
202 L       12
206 Y W       20       1
212 D
215 Y W       18       1
221 Y _        1       0
227 Y _        2       1
233 J      100      59
238 Y _        1   20000
244 Y IF       1       1        9         0
252 L       13
256 Y W       19       1
262 Y _        1       0
268 Y _        2       1
274 J      100      59
279 Y _        1   20000
285 Y IF       1       1        1         0
293 J       14      -1
298 J       11      -1
303 Y W       17       1
309 Y _        1       1
315 Y _        2     500
321 J      100      59
326 Y _       20   20000
332 MS      31     200
337 MS      21       6
342 J       13      -1
347 L       14

351 . .
```

```
  1 L     -50
  5 L     500
  9 Y W     14       1
 15 Y W     24       1
 21 D
 24 L        2
 28 CL       2
 32 CL       3
 36 CL       4
 40 CL       5
 44 L        4
 48 Y       71       0       2     500
 55 F        0       1
 60 CL       0       0
 65 CL       1       0
 70 SP       0       2       2
 76 CL       2     42D     41D
 82 Y W      97       1
 88 /        4     21D       0
 94 L        3
 98 CH       0       2       2
104 X>       6
108 TL
111 <
114 .
```

```
  1 L      -51
  5 L      510
  9 Y IF      43       1       2       0
 17 Y W       35       1
 23 J      580      -1
 28 Y W       15       1
 34 L      580
 38 Y BS      40
 43 Y IF      30       0       9       0
 51 Y     5838       2
 56 Y W       29       1
 62 Y _        1       0
 68 Y _        2       1
 74 J      100      59
 79 Y _        1   2000D
 85 Y     5838       1
 90 Y IF       1       1       1       0
 98 J      513      -1
103 Y W       22       1
109 /.    2000
113 Y _     2003   2001D
119 Y _     2005   2000D
125 Y W       23       1
131 /.    2000
135 /.      -1
139 Y _     2004   2001D
145 Y _     2006   2000D
151 L      511
155 Y IF    2003   2004D       2      -2
163 Y _     2004   2003D
169 Y _     2003   2001D
175 Y IF    2005   2006D       2      -2
183 Y _     2006   2005D
189 Y _     2005   2000D
195 L      512
199 Y A-    2000   2004D   2003D
206 Y _       30   2000D
212 Y :     2000
217 Y A+    2001   2003D   2000D
224 Y _       29   2001D
230 Y A-    2006   2006D   2005D
237 Y :     2006     40D   2006D
244 Y ;       33   2006D       2
251 Y *       32     32D     33D
258 L      513
262 Y *       31     32D     21D
268 Y     5838       2
274 Y W       24       1
280 Y _        1       1
286 Y _        2       2
292 J      100      59
297 Y _        3   2000D
303 Y IF       3       1       5       0
311 MS      32
315 Y W       27       1
321 D
324 MS      32
328 MS      22       2     31D
334 L      520
338 Y IF      43       1       2       0
346 J      540      54
351 J      530      -1
356 J      520      52


361 L      530
365 Y     5838       1
370 <
373 .
```

```
  1 L      -52
  5 L      520
  9 Y W       97       1
 15 Y W       28       1
 21 Y IF      29      30D       1        2
 29 Y A-      30      29D       2
 36 Y      41      29D       30D        0
 43 CL       3
 47 CL       4
 51 CL       5
 55 CL       6
 59 L      521
 63 Y       45       2        0        2
 70 Y       45       1        0        1
 77 D        5       4
 82 SP       1       2        2
 88 /      521     21D        0
 94 CH       1       2        2
100 X<       1
104 X>       6
108 X<       2
112 X>       1
116 X<       3
120 X>       2
124 X>       4
128 X>       3
132 X<       5
136 X>       4
140 X<       6
144 TL
147 <
150 .
```

```
  1 L      -53
  5 L      530
  9 Y W       34       1
 15 Y W       24       1
 21 D
 24 L        2
 28 CL       2
 32 CL       3
 36 CL       4
 40 CL       5
 44 L        4
 48 Y       71        0        2     500
 55 H1
 58 H1       1
 62 F        0       1
 67 CL       0       0
 72 CL       1       0
 77 SP       0       2        2
 83 CL       2     42D      41D
 89 Y W       97       1
 95 /        4     21D        0
101 L        3
105 CH       0       2        2
111 X>       6
115 TL
118 <
121 .
```

```
  1 L      -54
  5 L     540
  9 Y W      97       1
 15 Y W      28       1
 21 Y IF     29      30D       1       2
 29 Y A-     30      29D       2
 36 Y      41     29D     30D       0
 43 CL      3
 47 CL      4
 51 CL      5
 55 CL      6
 59 L     521
 63 Y      45       2       1       2
 70 Y      45       1       1       1
 77 D       5       4
 82 SP      1       2       2
 88 /     521     21D       0.
 94 CH      1       2       2
100 X<      1
104 X>      6
108 X<      2
112 X>      1
116 X<      3
120 X>      2
124 X>      4
128 X>      3
132 X<      5
136 X>      4
140 X<      6
144 TL
147 <
150 .
```

```
  1 L      -58
  5 L      100
  9 Y     5838       2
 14 Y W       10       1
 20 Y _        1       0
 26 Y BS      41
 31 Y '        2     41D       2
 38 J      100      59
 43 Y _       42   20000D
 49 Y W       11       1
 55 Y _        1       1
 61 Y _        2       2
 67 J      100      59
 72 Y _       43   20000D
 78 Y     5838       1
 83 <
 86 .
```

```
 1 L      -59
 5 L      100
 9 Y R      2000
14 Y IF     2000        10        6        1
22 L      101
26 Y W        99        1
32 Y P         1
37 Y W        98        1
43 Y P         2
48 J      100        -1
53 Y IF     2000        2D        1       -1
61 J      101
65 L      102
69 <
72 .
```

APPENDIX E

TEST CHAMBER CHARACTERIZATION DATA

TANK CHARACTERIZATION p. 1

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
	1	8/19	B	10,000	L066	L051	Y	N	—
					R051				—
					D056				—
					B063				—
2	Z1	8/19	Z	CF 781 DF 1.395	L066	L051	Y	Y	1
					R051				2
					D056				3
					B063				4
2	Z2	8/19	Z	CF 1221 DF 0.977	L066	L051	Y	Y	5
					R051				6
					D056				7
					B063				8

LAB AIR, FRONT REMOVED

TEMP: 23°C

TANK CHARACTERIZATION p. 2

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
2	Z3	8/19	Z	CF 1915 DF 1.628	L066	L051	Y	Y	9
					R051				10
					D056				11
					B063				12
2	Z4	8/19	Z	CF 2481 DF 1.221	L066	L051	Y	Y	13
					R051				14
					D056				15
					B063				16
2	Z5	8/19	Z	CF 3028 DF 1.628	L066	L051	Y	Y	17
					R051				18
					D056				19
					B063				20

LAB AIR, FRONT REMOVED

TEMP: 23° C

TANK CHARACTERIZATION p. 3

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
2	26	8/20	Z	CF 3525 DF 0.977	L066	L051	Y	Y	21
↓	↓	↓	↓	↓	R051	↓	↓	↓	22
↓	↓	↓	↓	↓	D056	↓	↓	↓	23
↓	↓	↓	↓	↓	B063	↓	↓	↓	24
2	27	8/20	Z	CF 4102 DF 1.950	L066	L051	Y	Y	25
↓	↓	↓	↓	↓	R051	↓	↓	↓	26
↓	↓	↓	↓	↓	D056	↓	↓	↓	27
↓	↓	↓	↓	↓	B063	↓	↓	↓	28
2	28	8/20	Z	CF 4639 DF 0.814	L066	L051	Y	Y	29
↓	↓	↓	↓	↓	R051	↓	↓	↓	30
↓	↓	↓	↓	↓	D056	↓	↓	↓	31
↓	↓	↓	↓	↓	B063	↓	↓	↓	32

LAB AIR, FRONT REMOVED

TEMPT: 24° C

TANK CHARACTERIZATION P. 4

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
2	Z9	8/20	Z	CF 5708 DF 1.628	L066	L051	Y	Y	33
					R051				34
					D056				35
					B063				36
2	Z10	8/20	Z	CF 5567 DF 0.814	L066	L051	Y	Y	37
					R051				38
					D056				39
					B063				40

LAB AIR, FRONT REMOVED

TEMPT: 24° C

TANK CHARACTERIZATION p. 1

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 781 Hz DELTA FREQ 1395 Hz
SET UP NO. E1 I.L. 4066 P.L. 4051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	691.0089	0.9304	40.3972
2	772.3085	0.4990	24.2164
3	1001.7299	0.3390	21.3372

REMARKS: DAMPING FACTOR
MEAN 0.4667
SDEV 0.3689

OVER ALL - 66 MODES
MEAN 0.4667
SDEV 0.3689

TANK CHARACTERIZATION p.2

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 1221 Hz DELTA FREQ 0.977 Hz
SET UP NO. 22 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	1154.2720	0.3666	26.5879
2	1209.6404	0.3617	27.4907

REMARKS:

MEAN 0.3642
SDEV 0.0035

TANK CHARACTERIZATION p. 3

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 1915 Hz DELTA FREQ 1.628 Hz
SET UP NO. Z3 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	1668.4983	0.9791	102.6449
2	1750.1306	0.9278	102.0324
3	1760.9746	0.5123	56.6821
4	1809.2222	0.8250	93.7859
5	1832.9678	0.8469	97.5367
6	1884.0430	1.4023	166.0180
7	1938.7812	0.8817	107.4156
8	2094.7720	0.7149	94.0988
9	2118.6519	0.7003	93.2241
10	2151.9443	1.1281	152.5360

REMARKS:

MEAN 0.8918
SDEV 0.2458

TANK CHARACTERIZATION R 4

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 2481 Hz DELTA FREQ 1.221 Hz
SET UP NO. 24 I.L. L066 P.L. L051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	2333.2114	0.9564	140.2137
2	2362.3042	1.6598	246.3983
3	2355.9790	0.8713	128.9780
4	2426.7603	0.4540	69.2302
5	2460.3726	1.5220	235.3064
6	2509.1226	0.1452	22.8930
7	2530.9097	0.9134	145.2596
8	2622.4209	0.3006	49.5311
9	2651.9224	0.8035	133.8858
10	2680.6084	0.8262	139.1604
11	2690.6641	0.3788	64.0429
12	2720.3945	0.0183	3.1309

REMARKS:

MEAN 0.7375
SDEV 0.5084

TANK CHARACTERIZATION p5.

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 3028 Hz DELTA FREQ 1.628 Hz
SET UP NO. Z5 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	2818.4990	0.6946	123.0181
2	3024.3071	0.5826	110.7128
3	3040.4941	0.2689	51.3782
4	3046.4717	0.2335	44.7014
5	3077.1182	0.4668	90.2463
6	3127.6680	0.0932	18.3111
7	3165.7607	0.4053	80.6185
8	3224.8081	0.1370	27.7577
9	3244.9121	0.4503	91.8050
10	3298.6997	0.2684	55.6223

REMARKS:

MEAN 0.3601
SDEV 0.1934

TANK CHARACTERIZATION P6

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 3525 Hz DELTA FREQ 0.977 Hz
SET UP NO. Z6 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	3473.6230	0.3050	66.5772
2	3499.4370	0.2700	59.3574
3	3504.3423	0.1178	25.9270
4	3535.8076	0.2239	49.7350
5	3540.3945	0.2986	66.4306
6	3689.9521	0.4422	102.5335

REMARKS:

MEAN 0.2763
SDEV 0.1065

TANK CHARACTERIZATION P. 7

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 4102 Hz DELTA FREQ 1.950 Hz
SET UP NO. 27 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	3708.0176	0.1563	36.4081
2	3739.4619	0.2886	67.8028
3	3978.8354	0.3270	81.7540
4	4175.1768	0.3055	80.1305
5	4304.8604	0.3084	83.4207
6	4268.5244	0.7869	211.0450
7	4373.2285	0.0283	7.7682
8	4397.8242	0.2911	80.4380

REMARKS:

MEAN 0.3115
SDEV 0.2176

TANK CHARACTERIZATION p. 8

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 4639 Hz DELTA FREQ 0814 Hz
SET UP NO. 28 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	4577.9502	0.1682	48.3874
2	4587.2305	0.2068	59.6131
3	4600.7148	0.2908	84.0604

REMARKS:

MEAN 0.2219
SDEV 0.0627

TANK CHARACTERIZATION P9.

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 5108 Hz DELTA FREQ 1.628 Hz
SET UP NO. 29 I.L. 4066 P.L. 4051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	4928.8633	0.1722	53.3310
2	4934.2207	0.0785	24.3374
3	5037.2158	0.1848	58.4919
4	5093.0049	0.2353	75.2850
5	5166.7334	0.1159	37.6096
6	5224.5625	0.3496	114.7615
7	5250.6016	0.2746	90.5984
8	5336.7764	0.1459	48.9310
9	5343.3770	0.0720	24.1772
10	5354.5029	0.1578	53.0726

REMARKS:

MEAN 0.1787

SDEV 0.0873

TANK CHARACTERIZATION p. 10

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 5567 Hz DELTA FREQ 0.814 Hz
SET UP NO. Z10 I.L. 6066 P.L. 6051

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	5600.1504	0.1289	45.3524
2	5713.8037	0.2031	72.9079

REMARKS:

MEAN 0.1660
SDEV 0.0525

TANK CHARACTERIZATION P. 1

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 781 Hz, DELTA FREQ 1.395 Hz
SET UP NO. 31, I.L. L066 P.L. L051

MODES	INTERVAL	LEVEL	ITER.
3	0 -100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	37.34	41.55	175.38	356
1	48.82	25.58	145.50	204
3	81.06	21.29	90.17	350

REMARKS:

TANK CHARACTERIZATION p. 2

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 1221 Hz, DELTA FREQ 0.977 Hz
SET UP NO. 22, I.L. L066 P.L. L051

MODES	INTERVAL	LEVEL	ITER.
2	0-100	10.00	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	36.59	25.16	87.80	4
1	47.91	28.10	367.14	184

REMARKS:

TANK CHARACTERIZATION p.3

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 1915 Hz, DELTA FREQ 1.628 Hz
SET UP NO. E3, I.L. L066 P.L. L021

MODES	INTERVAL	LEVEL	ITER.
10	0-100	10	5

MODE	FREQ.	DAMP	AMPL.	PHS
7	20.15	86.08	74.68	191
9	28.76	68.29	68.68	10
10	32.68	42.68	63.21	271
4	36.79	107.23	137.58	197
5	38.94	115.96	98.65	113
1	46.18	193.19	404.77	57
8	53.22	75.93	140.12	246
6	71.03	115.58	9.32	82
3	74.95	98.64	135.09	26
2	77.49	170.48	279.61	329

REMARKS:

TANK CHARACTERIZATION p. 4

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 2481 Hz, DELTA FREQ 1.221 Hz
SET UP NO. 24, I.L. 2066 P.L. 2051

MODES	INTERVAL	LEVEL	ITER.
12	0 - 100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
5	28.76	166.14	141.06	300
4	30.13	343.87	166.83	70
3	30.91	173.95	107.93	336
1	41.48	69.00	164.58	303
2	46.57	243.95	458.94	209
7	54.20	19.31	31.58	234
6	56.55	170.22	254.06	272
12	72.99	36.22	33.72	338
8	76.71	112.68	26.82	211
9	78.08	142.48	21.84	167
11	84.34	76.35	19.65	158
10	85.51	100.66	32.98	63

REMARKS:

TANK CHARACTERIZATION P 5

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 3028 Hz, DELTA FREQ 1.628 Hz
SET UP NO. 35, I.L. L06L P.L. L05L

MODES	INTERVAL	LEVEL	ITER.
10	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
9	24.46	127.22	22253	94
8	48.92	108.10	111.19	69
6	52.05	44.07	40.86	340
7	52.83	28.46	8.82	27
5	57.33	84.75	153.15	286
10	61.83	0.10	0.12	264
4	67.90	96.79	213.93	250
2	74.36	68.22	91.80	196
1	75.73	105.31	453.38	235
3	81.99	45.23	157.16	200

REMARKS:

TANK CHARACTERIZATION P. 6

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 3525 Hz, DELTA FREQ 0.977 Hz
SET UP NO. 26, I.L. 6066 P.L. 6056

MODES	INTERVAL	LEVEL	ITER.
6	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	40.31	81.47	246.87	83
3	43.05	91.47	65.73	64
4	45.98	22.54	92.39	56
5	46.77	99.42	59.41	151
6	56.16	48.94	76.57	62
1	82.97	109.30	472.35	336

REMARKS:

TANK CHARACTERIZATION p. 7

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 4102 Hz, DELTA FREQ 1.95 Hz
SET UP NO. 27, I.L. 2066 P.L. 2051

MODES	INTERVAL	LEVEL	ITER.
8	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
8	10.17	30.80	65.74	276
6	13.30	62.68	250.54	232
3	38.55	81.03	313.78	173
7	58.12	91.57	265.57	352
1	70.45	86.45	670.55	25
2	71.42	195.08	210.68	298
5	77.29	0.12	0.29	210
4	79.25	82.43	268.47	248

REMARKS:

TANK CHARACTERIZATION p. 8

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 4639 Hz, DELTA FREQ 0.8138 Hz
SET UP NO. 28, I.L. 6066 P.L. 6051

MODES	INTERVAL	LEVEL	ITER.
3	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	35.61	52.52	422.14	155
3	36.39	55.85	175.41	117
1	40.50	81.09	490.49	16

REMARKS:

TANK CHARACTERIZATION p. 9

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 5108 Hz, DELTA FREQ 1.628 Hz
SET UP NO. 29, I.L. 6066 P.L. 6051

MODES	INTERVAL	LEVEL	ITER.
10	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	28.76	52.25	531.95	354
3	29.15	25.24	196.69	316
5	44.03	115.76	563.75	261
1	48.14	83.04	1,203.13	165
4	56.16	56.47	369.27	5
10	63.79	56.13	162.05	355
7	66.73	120.25	724.33	290
6	77.49	25.62	315.20	266
9	78.47	3.91	51.77	354
8	79.45	65.62	178.66	252

REMARKS:

TANK CHARACTERIZATION p. 10

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 5567 Hz, DELTA FREQ 0.8138 Hz
SET UP NO. Z1Q, I.L. L066 P.L. L051

MODES	INTERVAL	LEVEL	ITER.
2	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
1	58.13	45.59	1,509.04	161
2	85.49	75.42	1,031.09	152

REMARKS:

APPENDIX F

SPECIMEN DAMPING MEASUREMENT DATA

SPECIMEN (FIXED) p. 1

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
—	—	8/20	B	25,000	A	X	Y	N	—
↓	↓	↓	↓	↓	B	↓	↓	↓	—
↓	↓	↓	↓	↓	C	↓	↓	↓	—
	LARGE HAMMER				(0 → ~6000 HZ)				
1	Z1	8/23	Z	CF 673 DF 1.395	A	X	Y	Y	146
↓	↓	↓	↓	↓	B	↓	↓	↓	147
↓	↓	↓	↓	↓	C	↓	↓	↓	148
1	Z2	8/23	Z	CF 1758 DF 4.883	A	X	Y	Y	149
↓	↓	↓	↓	↓	B	↓	↓	↓	150
↓	↓	↓	↓	↓	C	↓	↓	↓	151
1	Z3	8/23	Z	CF 2969 DF 1.953	A	X	Y	Y	152
↓	↓	↓	↓	↓	B	↓	↓	↓	153
↓	↓	↓	↓	↓	C	↓	↓	↓	154

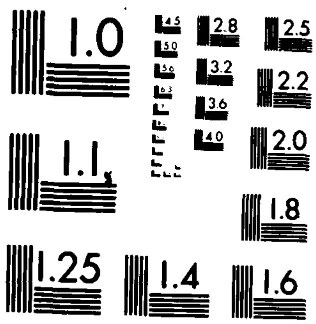
LAB AIR, FRONT REMOVED
SPECIMEN IN TEST CHAMBER

Temp: 24.5°C

AD-A132 701 THE DESIGN OF A TEST PROCEDURE FOR THE MEASUREMENT OF ACOUSTIC DAMPING OF MATERIALS AT LOW STRESS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R A HEIDGERKEN SEP 83 3/3

UNCLASSIFIED F/G 17/1 NL

END
DATE
FILMED
10 83
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SPECIMEN (FIXED) p.2

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
1	24	8/23	Z	CF 4277 DF 1.221	A	X	Y	Y	155
					B				156
					C				157
1	25	8/23	Z	CF 5508 DF 1.953	A	X	Y	Y	158
					B				159
					C				160
		SMALL	HAMMER		(0 → ~	12,000	HZ)		
2	26	8/23	Z	CF 6494 DF 4.069	A	X	Y	Y	490
					B				491
					C				492
2	27	8/23	Z	CF 8448 DF 6.104	A	X	Y	Y	493
					B				494
					C				495

LAB AIR, FRONT REMOVED

SPECIMEN IN TEST CHAMBER TEMP 24.5°C

SPECIMEN (FIXED) P. 3

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
Z	Z8	8/23	Z	CF 10,500 DF 4.883	A	X	Y	Y	496
					B				497
					C				498

LAB AIR, FRONT REMOVED
SPECIMEN IN TEST CHAMBER

TEMPT: 24.5°C

SPECIMEN (FIXED) P. 1

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 673 Hz DELTA FREQ 1.395 Hz
SET UP NO. 21 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	681.4570	0.1755	7.5124

REMARKS:

OVERALL - 26 MODES

MEAN 0.1112 } DAMPING FACTORS
SDEV 0.0601 }

SPECIMEN (FIXED) P.2

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 1758 Hz DELTA FREQ 4.883 Hz
SET UP NO. 22 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	1536.2964	0.2942	28.3967
2	2351.8062	0.1404	20.7464

REMARKS:

DAMPING FACTOR
MEAN 0.2173
SDEV 0.1088

SPECIMEN (FIXED) P. 3

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 2969 Hz DELTA FREQ 1.953 Hz
SET UP NO. 23 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	2801.5000	0.0517	9.1091
2	2942.3462	0.0631	11.6746
3	3065.4561	0.528	10.1619

REMARKS:

DAMPING FACTOR

MEAN 0.0559
SDEV 0.0063

SPECIMEN (FIXED) P. 4

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 4277 Hz DELTA FREQ 1.221 Hz
SET UP NO. 24 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	4196.2852	0.0865	22.8035
2	4278.3662	0.0900	24.1881

REMARKS:

DAMPING FACTOR
MEAN 0.0883
SDEV 0.0025

SPECIMEN (FIXED) p. 5

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 5127 Hz DELTA FREQ 1.953 Hz
SET UP NO. 25 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	5337.0332	0.1365	45.7660
2	5500.6924	0.0551	19.0292

REMARKS:

DAMPING FACTOR

MEAN 0.0958
SDEV 0.0576

SPECIMEN (FIXED) p. 6

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 6494 Hz DELTA FREQ 4.069 Hz
SET UP NO. X6 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	5969.4082	0.0806	30.2206
2	6002.8340	0.1114	42.0234
3	6043.4957	0.1873	71.1131
4	6228.8242	0.0777	30.4007
5	6262.8672	0.2065	81.2610
6	7233.7861	0.1227	55.7640

REMARKS:

DAMPING FACTOR
MEAN 0.1310
SDEV 0.0542

SPECIMEN (FIXED) p. 7

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 8448 Hz DELTA FREQ 6.014 Hz

SET UP NO. E1 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	7243.4170	0.1446	65.8016
2	7793.2168	0.0863	42.2623
3	7795.9941	0.0024	1.1673
4	7961.3145	0.1085	54.2597
5	9106.1777	0.1165	66.6824

REMARKS:

DAMPING FACTOR
MEAN 0.0917
SDEV 0.0541

SPECIMEN (FIXED) 1.8

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 10,500 Hz DELTA FREQ 4.883 Hz
SET UP NO. 28 I.L. A P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	9765.8281	0.0904	55.4538
2	9873.8906	0.1679	104.1932
3	10,042.2461	0.0874	55.1625
4	10,906.0996	0.0907	62.1313
5	11,062.8887	0.0636	44.2430

REMARKS:

DAMPING FACTOR

MEAN 0.1000
SDEV 0.0396

SPECIMEN (FIXED) p. 1

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 673 Hz, DELTA FREQ 1.395 Hz
SET UP NO. Z1, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
1	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
1	51.26	8.24	38.26	184

REMARKS:

SPECIMEN (FIXED) p. 2

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 1758 Hz, DELTA FREQ 4.883 Hz
SET UP NO. ZZ, I.L. A P.L. X

MODES 2 INTERVAL 0 -100 LEVEL 10.0 ITER. 5

MODE	FREQ.	DAMP	AMPL.	PHS
2	41.21	28.36	63.46	173
1	73.91	27.74	130.24	170

REMARKS:

SPECIMEN (FIXED) p. 3

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 2969 Hz, DELTA FREQ 1.953 Hz
SET UP NO. 23, I.L. A P.L. 8

MODES	INTERVAL	LEVEL	ITER.
3	0-100	8.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
1	33.29	12.95	314.20	357
3	47.42	12.23	126.99	7
2	59.79	10.55	136.20	359

REMARKS:

SPECIMEN (FIXED) P.4

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 42.77 Hz, DELTA FREQ 1.221 Hz
SET UP NO. Z4, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
2	0-100	12.99	5

MODE	FREQ.	DAMP	AMPL.	PHS
1	37.38	28.46	45.01	338
2	50.45	17.33	16.15	169

REMARKS:

SPECIMEN (FIXED) p. 5

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 5508 Hz, DELTA FREQ 1.953 Hz
SET UP NO. 55, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
2	0-100	12.99	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	32.98	45.62	140.52	176
1	49.42	20.75	141.13	160

REMARKS:

SPECIMEN (FIXED) p. 6

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 6494 Hz, DELTA FREQ 4.069 Hz
SET UP NO. 26, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
6	0-100	10.0	

MODE	FREQ.	DAMP	AMPL.	PHS
5	24.88	30.59	3.74	3
1	26.47	40.93	15.38	358
6	28.71	38.29	3.42	18
4	37.33	23.48	1.96	211
3	38.66	59.77	12.95	182
2	85.83	38.58	15.12	172

REMARKS:

SPECIMEN (FIXED) P 7

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 8448 Hz, DELTA FREQ 6.014 Hz
SET UP NO. XI, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
5	0-100	12.99	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	11.27	44.25	13.81	172
4	28.16	38.05	8.92	173
5	28.68	3.47	3.16	123
1	34.30	45.25	20.93	348
3	71.86	63.36	14.37	344

REMARKS:

SPECIMEN (FIXED) p. 8

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 10,500 Hz, DELTA FREQ 4.883 Hz
SET UP NO. 28, I.L. A P.L. X

MODES	INTERVAL	LEVEL	ITER.
5	0-100	12.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
4	20.80	54.45	25.66	175
5	25.18	116.34	47.36	135
3	31.76	49.52	28.80	351
1	66.38	49.25	60.00	192
2	72.52	88.17	75.16	168

REMARKS:

SPECIMEN (FREE) p.1

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
—	—	8/25	B	25,000	A	X	Y	N	—
—	—	↓	↓	↓	B	↓	↓	↓	—
—	—	↓	↓	↓	C	↓	↓	↓	—
	LARGE HAMMER (0 → ~6000 Hz)								
1	21	8/25	Z	CF 1524 DF= 2.441	A	X	Y	Y	1
↓	↓	↓	↓	↓	B	↓	↓	↓	2
↓	↓	↓	↓	↓	C	↓	↓	↓	3
1	22	8/25	Z	CF 2735 DF 4.883	A	X	Y	Y	4
↓	↓	↓	↓	↓	B	X	↓	↓	5
↓	↓	↓	↓	↓	C	X	↓	↓	6
1	23	8/25	Z	CF 4092 DF 3.255	A	X	Y	Y	7
↓	↓	↓	↓	↓	B	↓	↓	↓	8
↓	↓	↓	↓	↓	C	↓	↓	↓	9

SPECIMEN ON FOAM Rubber
LAB AIR, TEMPT: 21°C

SPECIMEN (FREE) p. 2

SETUP NO.	TEST NO.	DATE	TYPE (B or Z)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (Y or N)	STORE DATA (Y,N)	DATA LOC. (RECORD)
1	Z4	8/25	Z	CF 4951 DF 1953	A	X	Y	Y	10
					B	X			11
					C	X			12
	SMALL HAMMER (0 - 12,000 Hz)								
2	Z5	8/25	Z	CF 5493 DF 4.069	A	X	Y	Y	13
					B				14
					C				15
2	Z6	8/25	Z	CF 6738 DF 2.441	A	X	Y	Y	16
					B				17
					C				18
2	Z7	8/25	Z	CF 7935 DF 3.418	A	X	Y	Y	19
					B				20
					C				21

SPECIMEN ON FOAM Rubber

LAB AIR, TEMP: 21°C

SPECIMEN (FREE) p. 3

SETUP NO.	TEST NO.	DATE	TYPE (BorZ)	RANGE (MAX.FREQ) or (CF,DF)	INPUT LOC. (GRID NO.)	RESPONSE LOC. (GRID NO.)	FILTER (YorN)	STORE DATA (Y,N)	DATA LOC. (RECORD)
2	Z8	8/25	Z	CF 9009 DF 2.441	A	X	Y	Y	22
↓	↓	↓	↓	↓	B	↓	↓	↓	23
↓	↓	↓	↓	↓	C	↓	↓	↓	24
2	Z9	8/25	Z	CF 10,307 DF 4.883	A	X	Y	Y	25
↓	↓	↓	↓	↓	B	↓	↓	↓	26
↓	↓	↓	↓	↓	C	↓	↓	↓	27

SPECIMEN ON FOAM Rubber
LAB AIR, TEMP: 21°C

SPECIMEN (FREE) P. 1

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 1524 Hz DELTA FREQ 2441 Hz
SET UP NO. 21 I.L. B P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	1415.4900	0.084	7.4668
2	1761.7776	0.0930	10.3001

REMARKS: OVERALL - 28 MODES

MEAN 0.0885 MEAN 0.0500
SDEV 0.0064 SDEV 0.0504

SPECIMEN ON FOAM Rubber
LAB AIR T=21°C

SPECIMEN (FREE) P. 2

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 2235 Hz DELTA FREQ 4.883 Hz
SET UP NO. 22 I.L. ______ P.L. ______

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	1762.5181	0.1202	13.3060
2	2906.4292	0.2615	47.7560
3	2930.1177	0.0909	16.7370
4	2956.5010	0.0853	15.8496
5	3598.7559	0.0740	16.7333

REMARKS:

T=21°C

MEAN 0.1264
SDEV 0.0774
SPECIMEN ON FOAM Rubber

SPECIMEN (FREE) P. 3

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 4092 Hz DELTA FREQ 3.255 Hz
SET UP NO. E3 I.L. 8 P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	4322.3330	0.0339	9.2100

REMARKS:

T= 21°C

Specimen on Foam Rubber

SPECIMEN (FREE) p. 4

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 4951 Hz DELTA FREQ 1.953 Hz
SET UP NO. 34 I.L. B P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	5043.0186	0.0271	8.6007
2	5149.8730	0.0279	9.0214
3	5172.4209	0.0246	8.0086

REMARKS:

SPECIMEN ON FOAM Rubber T=21°C

MEAN 0.0265

SDEV 0.0017

SPECIMEN (FREE) P. 5

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 5493 Hz DELTA FREQ 4.069 Hz
SET UP NO. 25 I.L. B P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	5173.5977	0.0281	9.1474
2	5677.7148	0.0309	11.0148

REMARKS:

SPECIMEN ON FOAM Rubber T=21°C
MEAN 0.0295
SDEV 0.0020

SPECIMEN (FREE) P. 6

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 6738 Hz DELTA FREQ 2.44 Hz
SET UP NO. E6 I.L. 8 P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	6656.9932	0.0313	13.0864
2	7069.4844	0.0207	9.2144
3	7114.8486	0.0320	14.3134
4	7117.5123	0.0159	7.1033

REMARKS:

SPECIMEN ON FOAM RUBBER T=21°C

MEAN 0.0250

SDEV 0.0080

SPECIMEN (FREE) P. 7

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 7935 Hz DELTA FREQ 3.48 Hz
SET UP NO. 27 I.L. B P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	7717.5342	0.0104	5.0272
2	7759.0869	0.0535	26.0876
3	7796.1553	0.0168	8.2050
4	7808.3027	0.0509	24.9551
5	8111.0342	0.0337	17.1760

REMARKS:

SPECIMEN ON FOAM RUBBER T=21°C

MEAN 0.0331

SDEV 0.0195

SPECIMEN (FREE) p. 8

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 9009 Hz DELTA FREQ 2.441 Hz
SET UP NO. Z8 I.L. S P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	8678.7637	0.0350	19.0990
2	8909.0664	0.0131	7.3171
3	9140.6094	0.0145	8.2993

REMARKS:

SPECIMEN ON FOAM RUBBER T=21°C

MEAN 0.0209

SDEV 0.0123

SPECIMEN (FREE) P.9

AVERAGE MODAL FREQUENCIES AND DAMPING

CNTR FREQ 10307 Hz DELTA FREQ 4.883 Hz
SET UP NO. [illegible] I.L. B P.L. X

MODE	NAT. FREQ (Hz)	DAMP. FACT. (%)	DAMP. COEFF. (RAD/SEC)
1	9775.7812	0.0356	21.8801
2	9973.4199	0.0224	14.0266
3	11, 040.0918	0.0323	22.4213

REMARKS:
SPECIMEN ON FOAM Rubber T = 21°C
MEAN 0.0301
SDEV 0.0069

SPECIMEN (FREE) P. 1

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 1524 Hz, DELTA FREQ 2.441 Hz
SET UP NO. Z1, I.L. B P.L. X

MODES	INTERVAL	LEVEL	ITER.
2	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
1	41.39	7.93	121.58	177
2	69.19	9.28	56.54	10

REMARKS:

SPECIMEN (FREE) P. 2

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 2735 Hz, DELTA FREQ 4.883 Hz
SET UP NO. 22, I.L. 8 P.L. 3

MODES	INTERVAL	LEVEL	ITER.
5	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
4	11.12	14.03	85.35	357
5	57.12	34.41	53.82	242
2	57.94	17.87	173.22	345
1	59.96	17.26	249.11	355
3	84.15	15.37	116.13	347

REMARKS:

SPECIMEN (FREE) P. 3

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 409.2 Hz, DELTA FREQ 3.225 Hz
SET UP NO. 23, I.L. B P.L. X

MODES	INTERVAL	LEVEL	ITER.
1	0-100		

MODE	FREQ.	DAMP	AMPL.	PHS
1	63.97	6.95	276.79	170

REMARKS:

SPECIMEN (FREE) p. 4

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 4951 Hz, DELTA FREQ 6953 Hz
SET UP NO. 24, I.L. 6 P.L. X

MODES	INTERVAL	LEVEL	ITER.
3			

MODE	FREQ.	DAMP	AMPL.	PHS
2	59.26	11.19	26.31	216
3	70.07	9.30	14.81	343
1	72.31	3.89	34.12	252

REMARKS:

SPECIMEN (FREE) P. 5

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 5493 Hz, DELTA FREQ 4.069 Hz
SET UP NO. 25, I.L. B P.L. X

MODES	INTERVAL	LEVEL	ITER.
2	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	34.80	4.36	11.05	211
1	58.99	10.99	24.13	173

REMARKS:

SPECIMEN (FREE) p. 6

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 6738 Hz, DELTA FREQ 2441 Hz
SET UP NO. 26, I.L. B P.L. X

MODES	INTERVAL	LEVEL	ITER.
4	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
3	43.58	9.29	6.87	2
2	76.70	9.87	10.50	177
4	80.37	39.14	7.20	8
1	80.59	6.98	9.85	358

REMARKS:

SPECIMEN (FREE) p. 7

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 7935 Hz, DELTA FREQ 3.488 Hz
SET UP NO. 37, I.L. 5 P.L. X

MODES	INTERVAL	LEVEL	ITER.
5	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
5	37.85	18.45	6.63	199
3	40.13	19.61	6.87	174
2	42.34	4.41	4.72	8
1	43.06	15.86	11.02	348
4	59.97	18.87	8.61	182

REMARKS:

SPECIMEN (FREE) P. 8

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 9009 Hz, DELTA FREQ 2.441 Hz
SET UP NO. 21, I.L. 0 P.L. X

MODES	INTERVAL	LEVEL	ITER.
3	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	24.31	13.96	19.68	348
1	42.37	8.79	32.62	3
3	60.52	17.10	21.44	163

REMARKS:

SPECIMEN (FREE) p. 9

PRELIMINARY MODE IDENTIFICATION

CNTR FREQ 10307 Hz, DELTA FREQ 4.883 Hz
SET UP NO. 27, I.L. B P.L. X

MODES	INTERVAL	LEVEL	ITER.
3	0-100	10.0	5

MODE	FREQ.	DAMP	AMPL.	PHS
2	28.80	30.84	77.75	193
3	36.73	13.50	46.44	6
1	79.47	2337	80.50	167

REMARKS:

LIST OF REFERENCES

1. University of Dayton Research Institute, Vibration Damping Short Course Notes, Course Director: Drake, M.L., 1981.

2. Cremer, L. and Heckl, M., Structurborne Sound, Springer-Verlag, 1973.

3. Unger, E.E. and Kerwin, E.M., "Loss Factors of Visco-elastic Systems in Terms of Energy Concepts," Journal of Acoustic Society of America, v. 34, p. 954-957, July 1962.

4. Thomson, W.T., Theory of Vibration with Applications, 2nd ed., Prentice Hall, Inc., 1981.

5. Adams, R.D., and Fox, M.A.O., "Measurement of the Damping Capacity and Dynamic Modulus of High-Damping Metals Under Direct Cyclic Stresses," Journal of Physics, D: Applied Physics, v. 5, p. 1274-1283, 1972.

6. Hewlett-Packard, Modal Analysis Option 402, v 1A, chapter 11, p. 1-12, 1978.

7. Halvorsen, W.G. and Brown, D.L., "Impulse Technique for Structural Frequency Response Testing," Sound and Vibration, p. 8-21, November 1977.

8. Halvorsen, W.G. and Bendat, J.S., "Noise Source Identification Using Coherent Output Power Spectra," Sound and Vibration, vol. 9, no. 8, 1975.

9. Ramsey, K.A., "Effective Measurements for Structural Dynamics Testing--Part II," Sound and Vibration, vol. 10. no. 4, 1976.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Mr. E.J. Czyryca, Code 2814 David W. Taylor Naval Ship R&D Center Annapolis, Maryland 21402	2
4.	Mr. V.J. Castelli, Code 2844 David W. Taylor Naval Ship R&D Center Annapolis, Maryland 21402	2
5.	Department Chairman, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943	1
6.	Professor Y.S. Shin, Code 69Sg Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943	5
7.	Professor A.J. Perkins, Code 69Ps Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943	1
8.	LT Ricky A. Heidgerken c/o L.E. Steinbach 2448 Lauren Drive S.W. Cedar Rapids, Iowa 52404	3

ND

DATE
LMED

-83

DTIC